PERFORMANCE ANALYSIS OF A DYNAMIC BANDWIDTH ALLOCATION ALGORITHM IN A CIRCUIT-SWITCHED COMMUNICATIONS NETWORK

THESIS

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Abstract
Military communications networks typically employ a gateway multiplexer to aggregate all communications traffic onto a single link. These multiplexers typically use a static bandwidth allocation method via time-division multiplexing (TDM). Inefficiencies occur when a high-bandwidth circuit, e.g., a video teleconferencing circuit, is relatively inactive rendering a considerable portion of the aggregate bandwidth wasted while inactive. Dynamic bandwidth allocation (DBA) reclaims unused bandwidth from circuits with low utilization and reallocates it to circuits with higher utilization without adversely affecting queuing delay. The proposed DBA algorithm developed here measures instantaneous utilization by counting frames arriving during the transmission time of a single frame on the aggregate link. The maximum calculated utilization observed over a monitoring period is then used to calculate the bandwidth available for reallocation. A key advantage of the proposed approach is that it can be applied now and to existing systems supporting heterogeneous permanent virtual circuits. With the inclusion of DBA, military communications networks can bring information to the warfighter more efficiently and in a shorter time even for small bandwidths allocated to deployed sites. The algorithm is general enough to be applied to multiple TDM platforms and robust enough to function at any line speed, making it a viable option for high-speed multiplexers. The proposed DBA algorithm provides a powerful performance boost by optimizing available resources of the communications network. Utilization results indicate the proposed DBA algorithm significantly out-performs the static allocation model in all cases. The best configuration uses a 65536 bps allocation granularity and a 10 second monitoring period. Utilization gains observed with this configuration were almost 17\% over the static allocation method. Queuing delays increased by 50% but remained acceptable, even for real-time traffic.

Subject Terms
Dynamic Bandwidth Allocation, Circuit-Switched Communication, Time-Division Multiplexing, Tactical Military Communications Networks

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Abstract

Military communications networks typically employ a gateway multiplexer to aggregate all communications traffic onto a single link. These multiplexers typically use a static bandwidth allocation method via time-division multiplexing (TDM). Inefficiencies occur when a high-bandwidth circuit, e.g., a video teleconferencing circuit, is relatively inactive rendering a considerable portion of the aggregate bandwidth wasted while inactive. Dynamic bandwidth allocation (DBA) reclaims unused bandwidth from circuits with low utilization and reallocates it to circuits with higher utilization without adversely affecting queuing delay. The proposed DBA algorithm developed here measures instantaneous utilization by counting frames arriving during the transmission time of a single frame on the aggregate link. The maximum calculated utilization observed over a monitoring period is then used to calculate the bandwidth available for reallocation.

A key advantage of the proposed approach is that it can be applied now and to existing systems supporting heterogeneous permanent virtual circuits. With the inclusion of DBA, military communications networks can bring information to the warfighter more efficiently and in a shorter time even for small bandwidths allocated to deployed sites. The algorithm is general enough to be applied to multiple TDM platforms and robust enough to function at any line speed, making it a viable option for high-speed multiplexers. The proposed DBA algorithm provides a powerful performance boost by optimizing available resources of the communications network.

Utilization results indicate the proposed DBA algorithm significantly outperforms the static allocation model in all cases. The best configuration uses a 65536 bps allocation granularity and a 10 second monitoring period. Utilization gains observed with this configuration were almost 17% over the static allocation method. Queuing delays increased by 50% but remained acceptable, even for real-time traffic.

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I. Introduction

1.1 Motivation

The military's deployed communications network performance has long been hampered by the relatively low bandwidths allocated on the Defense Satellite Communications System (DSCS) constellation. Typical aggregate communications links over DSCS satellites range from 512 kbps to 1024 kbps. In contrast, typical Ethernet network data rates range from 10 Mbps to 100 Mbps, or even higher. With an increased reliance on communications systems to provide real-time data to the warfighter [DAF97, DAF98, DoD95, DoD00], it is imperative to increase performance wherever and however possible.

In traditional circuit-switched networks, bandwidth is generally allocated statically. This is especially true in military tactical networks, thus aggravating the problem of providing real-time information to the warfighter. In practice, this allocation scheme has a negative effect on network efficiency since some circuits may be rarely used. For instance, if a commander requests a video teleconferencing (VTC) circuit — a high-bandwidth circuit — it may only be used twice a day. If used for a one-half hour each time, there remains 23 hours each day that the dedicated circuit bandwidth is wasted.

Any increase in overall network utilization, however, must not be achieved at the expense of Quality of Service (QoS). In the static bandwidth allocation (SBA) scenario described above, QoS is not a problem since each circuit has dedicated bandwidth. Therefore, circuits needing guaranteed bandwidth, such as voice or video circuits, always have bandwidth when they need it [WaM99]. The question becomes: is it possible to increase overall network utilization while preserving QoS guarantees?

Asynchronous Transfer Mode (ATM) is a networking technology that was developed on the premise of optimizing performance for different classes of traffic based on QoS guarantees. For example, a voice circuit can tolerate some loss but not delay; conversely, a data circuit can tolerate delay but not loss. By identifying these different classes of traffic, ATM switches (or multiplexers) can provide the service that the class requires.

Recent advances in ATM technology have taken QoS guarantees one step further, supporting dynamic bandwidth allocation (DBA) [Sai97, Shi98, SCY98, WaM99]. DBA allows circuits access to unused bandwidth, thereby using bandwidth more efficiently. Hoe states, "The objective of ATM switching is to statistically multiplex traffic from different users (assign bandwidth on demand), to utilize bandwidth efficiently, and to satisfy the QoS requirements of delay and loss for different traffic types" [Hoe94]. Given the scenario outlined above, the VTC circuit would consume the maximum bandwidth it requests when in use; when not in use, the bandwidth could be allocated to other circuits based on demand.

Unfortunately, the Air Force's communications networks are not built using this principle. Currently, both fixed and deployed bases use NET's Promina system, which uses the Integrated Digital Network Exchange (IDNX), a Time-Division Multiplexer, to perform this gateway multiplexing function [DIS99]. We will use the terms Promina and IDNX interchangeably.

1.2 Problem Definition

1.2.1 Hypothesis and Goals. This study shows that a proposed DBA algorithm employed by platforms like ATM can be migrated to a time-division multiplexer (TDM) platform as a relatively low-impact addition. By using a DBA algorithm for individual circuits, utilization on the aggregate link of the Air Force's deployed networks can be drastically improved. However, increasing utilization is not the only consideration. For example, even if a particular implementation could consistently maintain utilization near 100%, it would be unacceptable if the bandwidth reallocation time were significantly higher than without dynamic allocation, resulting in a significant increase in queuing delay [SCY98]. The central hypothesis of the study, then, is that DBA on a TDM platform can achieve higher utilization on its aggregate link than static allocation without adversely affecting queuing delay. The goals of the study are the following:

- Determine whether dynamic bandwidth allocation algorithms can increase utilization on the aggregate link of a circuit-switched network,
- Determine whether increased utilization can be achieved without increasing queuing delay beyond acceptable limits,
- Determine whether the type of traffic influences the allocation algorithm performance.

1.2.2 Approach. A newly proposed DBA algorithm is developed for a time-division multiplexer based upon previously developed DBA algorithms for ATM. Several workloads are submitted to a network using the DBA algorithm as well as using static allocation. Using the static allocation as a baseline, the results are compared using aggregate utilization and queuing delay metrics.

1.3 Document Overview

This chapter presents the problem and the motivation for the research. Chapter 2 reviews previous research in the areas of ATM and DBA that serves as a point of departure for this study. Chapter 3 covers the methodology and experimental design used to validate the hypothesis. Chapter 4 describes the algorithm developed and analyzes the results obtained from the experiments. Chapter 5 summarizes the research results and provides conclusions and recommendations for future research.

II. Literature Review

This chapter begins with an overview of circuit-switching concepts. It then covers high-speed networking using Asynchronous Transfer Mode (ATM). Next, four theoretical models for dynamic bandwidth allocation in an ATM network will be covered along with their potential for portability to the Integrated Digital Network Exchange (IDNX). Finally, an overview of the IDNX is given.

2.1 Circuit-Switched Networks

There are two types of switching in communications networks — circuit switching and packet switching. Packet switching makes a routing decision at every node (or hop) between the sender and receiver. Consequently, the actual path that each packet takes may be different. Furthermore, bandwidth tends to be allocated on a first-come, first-served basis. By contrast, circuit switching establishes a specific route, or circuit, from sender to receiver at the time the message is transmitted. Bandwidth is usually allocated in "chunks" based on the circuit's bandwidth request. A connection admission control scheme is employed to determine whether the call can be admitted at the requested bandwidth. This can be done using relatively simple computations. The connection admission control algorithm first computes the bandwidth in use by computing the sum of the bandwidths of the individual circuits already allocated. It then computes the residual bandwidth by subtracting the bandwidth in use from the channel capacity. If the bandwidth requested is less than the residual bandwidth, the circuit is admitted. If not, it is rejected. There are also other schemes used in admission control including statistical multiplexing [Hoe94] and priority allocation [SWS98]. Circuit switching can be further broken down into conventional circuit switching and virtual circuit switching.

2.1.1 Conventional Circuit Switching. Conventional circuit switching is the type of switching used in traditional telecommunications networks. Under this model, a user sends a request for a connection of a specified bandwidth to the connection admission control. If this bandwidth request is less than the residual bandwidth, then the connection is admitted and a physical circuit is established, setting aside a fixed bandwidth for the connection. That circuit and associated bandwidth is then dedicated to the sender and receiver for the duration of the connection; no sharing of that bandwidth is done. This means that any idle time during the connection results in wasted bandwidth. Conventional circuit switching also has no concept of framing [Bla95] – the message is treated as one continuous data stream. When the channel is idle, no data is sent, except for perhaps a synchronization signal. Consequently, because data messages need to be delimited in order to be understood, this type of circuit switching is not a viable option for an all-purpose network supporting voice, video, and data.

2.1.2 Virtual Circuit Switching. Virtual circuit switching is a hybrid of conventional circuit switching and packet switching. Like conventional circuit switching, a specific path is established at the time of connection setup and remains for the duration of the connection. However, like packet switching, virtual circuit switching breaks the message up into packets for transmission and packets are transmitted at channel capacity [Tan96]. Framing allows data messages to be delimited, thus making it a viable implementation for supporting voice, video, and data concurrently. Connection setup is done in much the same way as conventional circuit switching. A user sends a request to admission control, a path is established between source and destination, and the connection is admitted. However, instead of a physical connection between a sender and receiver, a path through specific nodes is determined, constituting the virtual circuit. Whenever a packet arrives at a node, then, the node knows where to route the next packet based on a virtual circuit identifier. However, the virtual circuit is not guaranteed a specific bandwidth. In order to deal with this problem, many networking technologies such as ATM have implemented quality of service guarantees. These guarantees work in much the same manner as in conventional circuit switching. This is discussed in greater detail below.

2.2 Virtual Circuit Switching Using ATM

Asynchronous Transfer Mode is a high-speed virtual circuit-switching technology that was developed to support a heterogeneous mix of traffic classes, while providing an appropriate or a requested quality of service guarantee [Bla95]. The following paragraphs describe the basic frame format ATM uses, the basic classes of traffic that ATM supports, and how ATM guarantees quality of service.

2.2.1 Frame Format. ATM frames are called cells. Each cell is 53 bytes, consisting of 48 bytes of payload and a 5-byte header. The cell provides little in the way of services, including error checking on the header only, and no retransmission services. Three bytes of the 5-byte header contain the virtual circuit identifier for the user-to-network interface (3.5 bytes for the network-to-network interface). This is further broken down into a virtual channel identifier and a virtual path identifier. The virtual channel identifier identifies the specific circuit traversing the node. The virtual path identifier identifies a group of virtual channels that can be switched as a single unit. Together these two identifiers mark the route the cell travels through the network. The header also contains a Cell Loss Priority bit. If this bit is set, it indicates that the network can discard this cell if necessary, such as during heavy congestion [Tan96].

2.2.2 Traffic Classes. ATM divides user traffic into three major classes depending upon arrival rate — constant bit rate (CBR), variable bit rate (VBR), and available bit rate (ABR) to support different user applications [Bla95]. CBR consists of connection-oriented data streams in which cells arrive at a fixed rate and require timing synchronization between sender and receiver. An example of a CBR circuit would be a dedicated video teleconferencing circuit where new video frames are being transmitted continuously. VBR consists of connection-oriented data streams in which cells do not arrive at a fixed rate, but a peak cell rate must be guaranteed, and also require timing synchronization between sender and receiver. An example of a VBR circuit would be a telephone circuit. Clearly, cells would not be arriving at a continuous rate because idle periods in the conversation would not generate a cell transmission. However, a minimum peak data rate (based on the CODEC being used) must be maintained if a full-duplex call is to be established and telephony standards are to be upheld. ABR is like VBR except that there is no guaranteed peak cell rate. An example of an ABR circuit would be a typical IP data network.

2.2.3 Quality of Service Guarantees. Since two of the three major classes of ATM require a quality of service guarantee, it is important to understand how the guarantee is implemented. When a user wishes to establish a connection, he sends a message to admission control with a request for a certain level of service. This level of service comes in the form of a bandwidth request based on the type of circuit. The amount of bandwidth requested is usually based on the required peak cell rate of the circuit [WaM99, SCY98]. Thus, bandwidth has traditionally been allocated statically at the peak cell rate to guarantee the desired quality of service.

2.3 Dynamic Bandwidth Allocation in ATM

It is clear that any type of traffic with other than a constant cell rate will result in some amount of wasted bandwidth. In fact, "with bursty traffic, the average rate of the cell stream over a virtual circuit is low compared to the peak rate" [SCY98]. With the widespread proliferation of ATM as a wide-area network backbone, many approaches have been used to harness this wasted bandwidth. We discuss four strategies, two of which could be ported to a time-division multiplexing (TDM) platform such as the IDNX.

2.3.1 Intelligent Multiplexing. One method for improving bandwidth efficiency was proposed by Benjamin Hoe [Hoe94]. His method calls for an intelligent multiplexer to multiplex data and voice traffic together more efficiently.

2.3.1.1 Algorithm Overview. Since voice circuits cannot tolerate delay, but data circuits can, the multiplexer forwards voice cells immediately. Data cells are stored in a buffer upon arrival. Whenever the multiplexer detects an idle bit pattern (i.e., one with only idle fill), the multiplexer drops the idle cell and inserts a data cell. Once another voice cell arrives, data cells will be blocked again until an idle cell is detected. An example of this operation is shown in Figure 2.1 below. In the figure, voice cells are depicted as clear, data cells as shaded.

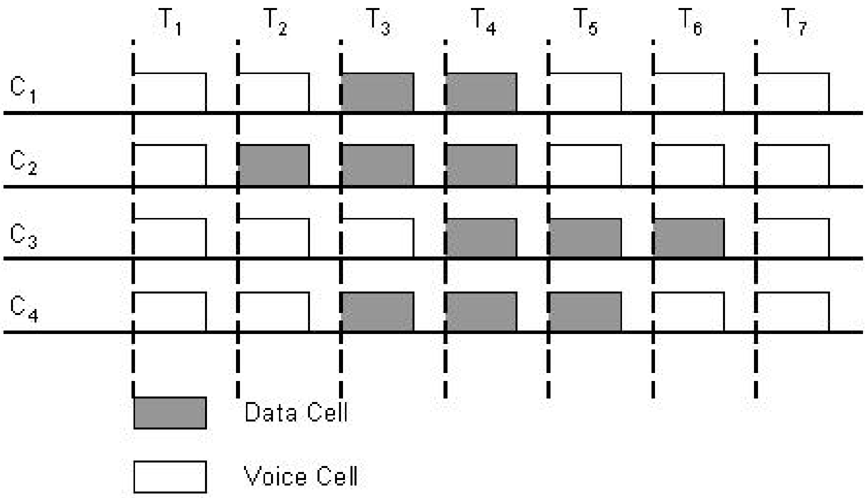

Figure 2.1. Intelligent Multiplexing Example

At T_1, all circuits (C_1 - C_4) have voice cells to be forwarded. At T_2, suppose C_2 sends an idle cell. That cell is discarded and replaced by a data cell as shown. At T_4, suppose all circuits send idle cells; four data cells are inserted in their place.

2.3.1.2 Advantages and Disadvantages. Because voice traffic tends to be quite bursty, data traffic would have ample opportunity for transmission during idle periods on the voice circuit. Therefore, it is conceivable that the bandwidth allocated to the data circuit could be eliminated with little effect on network performance. Furthermore, this algorithm is quite simple to implement.

It has, however, several significant drawbacks. First, it is overly simplistic. The algorithm assumes that there is only one data circuit. In practice, today's tactical networks usually have at least two — Non-secure Internet Protocol Routed Network (NIPRNET) and Secure Internet Protocol Routed Network (SIPRNET). It also assumes that the only two types of traffic on a communications network are voice and data. This assumption ignores the possibility of a CBR video circuit, such as a dedicated VTC link.

Second, in this scheme, voice circuits always have priority over the data circuit. Because voice circuits cannot tolerate delay, voice cells are transmitted first. Therefore, during heavy call volumes it is possible that data traffic would experience a significant delay. Furthermore, today's communications networks need the ability to prioritize circuits dynamically, for example, when critical intelligence or weather data is needed. In this situation, voice communication would not be the communications method of choice.

Finally, it would be difficult to port this algorithm to another platform. In this algorithm, each receiving node along the path must determine whether the information is a voice or data cell. Suppose that a multiplexer's frame format does not distinguish between information types. Each frame would be tied to a specific circuit but not necessarily a circuit of a specific information type. Thus the multiplexer is unable to determine at the receiving end which frames contain voice and which contain data.

2.3.2 Adaptive Bandwidth Demand Estimation. Shioda's adaptive bandwidth demand estimation algorithm is similar to that of Shiomoto, et al. discussed later. This algorithm monitors the active circuits for a set period and adapts the amount of available or residual bandwidth based on the blocking probabilities of the individual circuits [Shi98]. Blocking probability can be used as an effective metric because the blocking probability will increase as available bandwidth is depleted, thus indicating a greater bandwidth demand.

2.3.2.1 Algorithm Overview. Consider L active and potential circuits to be multiplexed on a virtual path. The aggregate offered load, a, and aggregate connection blocking probability, b, are defined as

$$a = \sum_{l=1}^{L} a_l m_l \tag{2.1}$$

and

$$b = \frac{\sum_{l=1}^{L} a_l m_l b_l}{a} \tag{2.2}$$

where a_l is the offered load and b_l is the connection blocking probability of the lth circuit. The effective bandwidth, m_l, is a weighting factor based on some constraint such as a QoS requirement [DKW95, Shi98]. This factor remains constant for a particular circuit for as long as the constraint holds.

Circuit admissions are decided differently depending on whether the new circuit is a CBR or VBR circuit. If the circuit to be added is a CBR circuit, then the admission decision is simple: compare the peak cell rate of the new circuit to the residual bandwidth. If the peak cell rate of the new circuit is less than the residual, then the circuit is admitted; otherwise it is rejected. If the circuit is a VBR circuit, though, calculation of the cell loss rate is needed for comparison against an objective cell loss rate, ε_{obj}. This calculation is given by

$$
\begin{aligned}
&\hat{\varepsilon} = \frac{1}{n\hat{A}} \sum_{k=1}^{K} \left[k\hat{M} - (K+1)\right]^{+} \cdot \begin{pmatrix} n \\ k \end{pmatrix} \left(\frac{\hat{A}}{\hat{M}}\right)^{k} \left(1 - \frac{\hat{A}}{\hat{M}}\right)^{n-k} \\
&\hat{M} = \left\lceil \frac{(K+1)M}{C} \right\rceil \\
&\hat{A} = \frac{(K+1)A}{C} \\
&[x]^{+} \equiv \min(x, 0)
\end{aligned}
\tag{2.3}
$$

where n is the number of connections multiplexed in the virtual path, K is the buffer size in cells, M is the peak rate in cells per second, A is the average rate in cells per second, and C is the number of cells that can be transmitted over the virtual path in one second. If $\hat{\varepsilon}$ is lower than ε_{obj}, then the VBR circuit is admitted. Otherwise it is rejected.

At the end of each measurement period, the connection blocking probability, b, is measured. Each VP bandwidth is then adjusted based on the following formula:

$$
\Delta\alpha_{t+1} = \begin{cases} r\alpha_t, b > b_{obj} \\ -r\alpha_t, b \leq b_{obj} \end{cases} \tag{2.4}
$$

where

$$
r = \max\left(0.1, \frac{b - b_{obj}}{1 - b}\right), \tag{2.5}
$$

b_{obj} is the maximum desired blocking probability, and α_t is the VP bandwidth demand for the last measurement period. This process repeats at the end of every measurement period.

2.3.2.2 Advantages and Disadvantages. This algorithm is very robust because it makes very few assumptions about the underlying traffic. Thus, it can support almost any type of connection [Shi98]. Second, the bandwidth demand estimate is adaptive, meaning that long-term traffic patterns are factored in making the model more reliable.

It has three disadvantages, one of which is very significant. First, the model requires that all circuits have some sort of quality of service guarantee either CBR or VBR. This is not an insurmountable problem, however, because even data networks can be modeled as a VBR circuit by assigning a minimum acceptable bandwidth to the data circuit. This minimum bandwidth effectively translates to a quality of service guarantee. The second disadvantage is that the calculations needed for this algorithm are complex. Therefore, an implementation would likely require some special purpose or dedicated hardware. Finally, many of the values used as input to these calculations either require further calculation or information that might not be available in a non-ATM environment. Consequently, it would be difficult to port this algorithm to a TDM platform.

2.3.3 Instantaneous Virtual Path Utilization Measurement. Shiomoto, Chaki, and Yamanaka propose to allocate bandwidth dynamically using a measurement of instantaneous virtual path utilization [SCY98].

2.3.3.1 Algorithm Overview. The instantaneous virtual path utilization is defined as

$$\rho(t) = \sum_{l=1}^{L} \frac{R_l(t)}{C} \tag{2.6}$$

where R_l(t) is the peak rate of the lth circuit at time t, and C is the channel capacity. In order to compute this instantaneous utilization, the number of cells arriving during one cell transmission period, Δ, are counted. This number is sent through an exponential averager to determine the instantaneous virtual path utilization. Thus, the instantaneous utilization can be rewritten as

$$\rho(t) = \alpha n(t) + (1-\alpha)\rho(t-\Delta), 0 \leq \alpha \leq 1 \tag{2.7}$$

where $n(t)$ is the number of cells that arrived in the last Δ seconds, ρ(t-Δ) is the last computed utilization, and α is a weighting factor. This value will be discussed in more detail in the next section.

The utilization is tracked for a monitoring period, T_m. The maximum utilization value observed during T_m, ρ_{max}, serves as the basis for the admission criteria. The admission criteria is then given as

$$\frac{R}{C} < 1 - \rho_{\max} \tag{2.8}$$

where R is the peak rate of a new circuit requesting bandwidth. If the new circuit is accepted, the computed virtual path utilization is updated as follows:

$$\rho_{new} = \rho_{\max} + \frac{R}{C} \tag{2.9}$$

If the request is rejected, then ρ_{max} remains the basis for admission of new circuits.

2.3.3.2 Weighting Factor α. The value of α determines whether the current measurement or past measurements is more significant. As α approaches 1, current measurements become more significant. Conversely, as α approaches 0, the amalgamation of past measurements becomes more significant. Because of the bursty nature of most circuits, it would typically be better to make α closer to 0. For example, simulation results from Shiomoto, et al. indicate that an α of 4.156E-3 will produce a very accurate representation of the system's instantaneous utilization for a virtual circuit with a peak rate of 10 Mbps [SCY98]. In general, α can be determined by

$$\alpha = \frac{-2(1-K) + \sqrt{4(1-K)^2 + 8\left(\varepsilon^{-1}-1\right)(1-K)}}{2\left(\varepsilon^{-1}-1\right)} \tag{2.10}$$

where ε is the cell loss rate, $K = \cos(2\pi f_0 \Delta)$, f_0 is the circuit's peak cell rate, and Δ is the time necessary to transmit a single cell on the aggregate link.

2.3.3.3 Monitoring Period T_m. The monitoring period should be sufficiently long to keep the cell loss rate below its target value. According to [SCY98], this value will be on the order of 100 seconds. If necessary, this period can be reduced but will result in sacrificing approximately 20% of the assignable channel capacity. For a more detailed explanation of T_m selection, refer to [SCY98].

2.3.3.4 Advantages and Disadvantages. This algorithm has several strengths. First, the algorithm is very simple. Once the maximum virtual path utilization is obtained for the monitoring period, the admission control need only compare the requested peak rate of the new circuit to the residual bandwidth. If this value is less, then the circuit is accepted; otherwise it is rejected. Second, because the algorithm relies on a simple cell count to calculate the instantaneous utilization, it can be completely implemented in software. Therefore, it is possible to port this algorithm to multiple platforms including TDM. In fact, implementation costs would be low if the multiplexer already has the capability to count incoming frames and to perform floating point operations. Further, because the algorithm is simple, the admission decision is fast, thus minimizing cell delay due to an admission decision.

A couple of disadvantages exist, however. First, the main reason that the algorithm is so easy to implement in hardware is that it assumes homogeneous circuits with homogeneous peak cell rates. This assumption obviously does not hold in practice. Therefore, either α would need to be dynamically adjustable, or multiple filters would be required — one for each circuit. While this problem is not insurmountable, it will raise the implementation cost. Second, the algorithm assumes that circuits are dynamically connected and disconnected, thus creating a dynamic amount of available bandwidth. However, in a military communications network, many circuits, such as data circuits, are persistent. Therefore, it would be advantageous to adjust previously allocated bandwidth dynamically. This problem is also fairly easy to overcome. As long as the circuit's current peak rate is known, only one additional computation would be required. In order to determine admission suitability, the old bandwidth would have to be subtracted off from ρ_{max} before the new peak rate could be compared to the residual bandwidth.

2.3.4 VP Bandwidth Control. Saito presents an algorithm [Sai97] very similar to that developed by [SCY98]. However, Saito's is much simpler and can be completely implemented in software.

2.3.4.1 Algorithm Overview. The virtual path bandwidth in use is approximated by counting the number of cells arriving during a measurement period. Let the channel capacity be divided into n levels. A particular bandwidth falls into a level i such that $x_{i-1} \leq x(t) < x_i$, where x_{i-1} and x_i are defined constants. Let $x(t)$ be the measured bandwidth in use at time t, such that $x(t)$ is in level i. The measured bandwidth in use is derived using Equation 2.11, where

$$x(t) = \frac{424n(t)}{T_m} \tag{2.11}$$

where $n(t)$ is the number of cells counted during the measurement period, T_m. The scalar, 424, represents the number of bits in one ATM cell.

Further, let

$$y(t|i) = x(t) - x(t-1) \tag{2.12}$$

Thus $y(t|i)$ is the difference in the current and previous bandwidth in use for level i. Define

$$y_i = \max\left(y(t|i)\right) \tag{2.13}$$

as the maximum difference observed during the previous measurement periods. The virtual path bandwidth in use during the next update interval is then given by

$$x_{\text{mod}}(t) = x(t) + y_i \tag{2.14}$$

and is an estimate of the bandwidth needed during the next update interval. This estimate is sufficient provided that the value of y_i is no greater than the value of y_i during the last update interval.

2.3.4.2 Advantages and Disadvantages. This algorithm's primary strength is its simplicity. It relies on a mere count of the arriving cells during a measurement period. This algorithm could also be completely implemented in software. In fact, implementation costs would be low assuming that the multiplexer already has the capability to count incoming frames. Consequently, it could be easily ported to a non-ATM platform such as the IDNX with little other than a software upgrade.

The algorithm's primary strength is also its primary weakness, however. Because it is possible for the amount of variation in the next measurement period to exceed that of the previous period, then any quality of service-guaranteed circuits could suffer until the system adapts. According to Saito's test bed measurement results, however, this problem occurs infrequently and the system adapts quickly. For example, this problem occurred only once in a four-day test and the system recovered by the next measurement period [Sai97]. The difference between this algorithm and the Shiomoto algorithm is that this one relies only on two measurements —

the current and previous measurements. The Shiomoto algorithm uses exponential averaging to account for all previous measurements as well as the current measurement. Therefore, the measured bandwidth in use might be less accurate than using the Shiomoto algorithm.

2.4 IDNX Operation

2.4.1 IDNX Virtual Circuit Switching. NET's Promina 800 series platform is a state-of-the-art resource manager [NET98] used by the Air Force as well as other DoD organizations. It includes the Integrated Digital Network Exchange (IDNX), which acts as a gateway communications multiplexer at both fixed and deployed sites. Its capabilities include time-division multiplexing (TDM), routing, switching, and network management functions for all classes of traffic [Gum96].

The IDNX can accept any combination of CBR, VBR, and ABR connections based on the node's card complement. Each of these connections can be viewed as a virtual circuit and are multiplexed using Time-Space-Time (TST) switching [NET96b]. The TST switching technique is depicted in Figure 2.2 below.

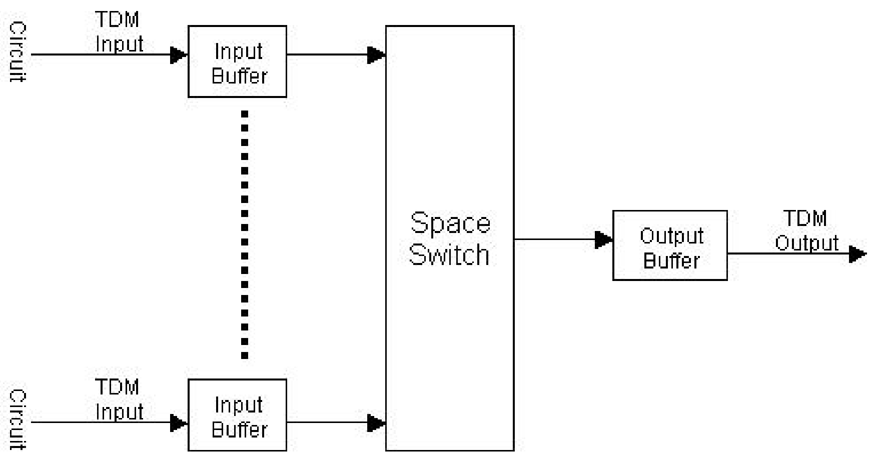

Figure 2.2. Time-Space-Time Switching

Using TST switching, data from each circuit is transported to the space switch via the data bus using TDM. The space switch then routes the frame to the appropriate outbound link and assigns it a time slot. If a single outbound link is used, then the space switch becomes a degenerate case in which all inbound frames are routed to the same outbound link.

2.4.2 Framing and Overhead. The TST switching function takes place on a trunking module — the heart of the multiplexer. Its purpose is to take the data arriving off the IDNX's internal data bus and repackage it more efficiently on the outgoing aggregate link. The data is repackaged into a framing format defined by the type of trunk module used. The Air Force's standard trunk module employed in its tactical networks is the SA-TRK module, which uses a proprietary framing format. The frame includes two types of overhead, Signaling Channel Link Protocol (SCLP) and standard framing overhead [NET96c].

The SCLP is used for inter-nodal communications. For instance, SCLP is used extensively for call setup and teardown as well as dynamic routing functions. SCLP overhead is user-selectable on the SA-TRK module at levels 8, 16, and 64 kbps. However, because SCLP overhead is used extensively for rerouting calls in the event of a trunk failure, choosing a small value may cause performance problems.

Because the IDNX uses a unique framing format, a separate framing channel is needed to properly reconstruct the data at the receiving end. On the SA-TRK module, the size of this overhead ranges from 4 to 12 kbps.

2.4.3 Connection Routing and Processing. Each circuit the IDNX multiplexes consists of one or more connections. In the case of a data circuit, the entire circuit can typically be viewed as a single permanent connection. By contrast, voice circuits are typically comprised of several sub-connections that are set up and torn down dynamically. Each of these sub-connections rides on top of a dedicated voice circuit, however. Setting up a connection in the IDNX consists of connection routing and connection processing [NET96b]. At connection setup time, the connection routing function determines the path from source to destination based upon link congestion and user-specified link preferences. Once the path is determined, if the receiving node is capable of accepting the connection, a virtual circuit is established and remains until a disconnect request is made by either end.

2.4.4 Bandwidth Allocation and Reservation. The IDNX's primary bandwidth allocation scheme is static allocation via TDM. Under static allocation, bandwidth is allocated to each circuit at the time the circuit is established. However, the IDNX also has a limited dynamic bandwidth allocation strategy called bandwidth reservation [NET96a, NET96b]. These strategies have two significant limitations.

First, bandwidth can only be reserved for intra-domain connections. Promina networks are divided into domains of up to 250 nodes [NET96a]. This can be done for a variety of purposes such as decentralizing network management. If a connection's destination node is assigned to a different domain, bandwidth cannot be reserved on that connection. Fortunately, this is less of a problem for tactical networks because for satellite connections the destination node is at the Standardized Tactical Entry Point (STEP), the satellite terminal's reachback facility. The STEP is the deployed site's entry point into the Defense Information Infrastructure.

Second, and more significant, is that bandwidth can only be reserved on new connections; the IDNX cannot adjust the bandwidths of established connections [NET96a]. Because many circuits, such as data circuits, are permanent their bandwidth can not be adjusted. Thus, any potential performance gain using bandwidth reservation on non-permanent circuits would be insignificant.

2.4.5 ATM on the IDNX. NET has also introduced an ATM capability for the Promina – the CellXpress module, which allows the Promina to function as an access device to an ATM network. The module converts out-going data into ATM cells and forwards the cells on to their destination. This capability certainly provides more flexibility to the Promina since it could then interface to either an IDNX network or an ATM network as needed. However, there are several disadvantages hindering the Air Force's wholesale integration. First, while the Air Force is gradually converting its backbone to ATM, it will still be about three to five years before this capability is widely available [DAF00]. Second, the CellXpress Module only supports Permanent Virtual Circuits. Therefore, Switched Virtual Circuits such as VTC circuits that are only established as needed would not be supported. Finally, the CellXpress module only interfaces with Packet Exchange-compatible modules [NET00], which the Air Force does not currently use.

2.5 Chapter Summary

Traditional telecommunications networks have employed conventional circuit switching, which provides a dedicated circuit for the duration of the connection. Virtual circuit switching is a method of providing a circuit-switching interface on a packet-switched network. It breaks messages up into packets and routes them across the network over a predetermined path. Rather than each virtual circuit being dedicated to the user for the duration of the connection, however, packets are statistically multiplexed onto the outgoing link.

ATM is a high-speed networking technology that employs virtual circuit switching and is capable of integrating voice, video, and data services on the same network. In order to provide users with a quality of service comparable to that of conventional circuit switching, however, bandwidth has traditionally been allocated statically. Several dynamic bandwidth allocation algorithms have been proposed, though, in order to more efficiently utilize available bandwidth. Four of these algorithms were presented and analyzed in this chapter.

Finally, the Promina is a resource manager employed by the Air Force and other DoD agencies. Like ATM, it is capable of integrating voice, video, and data services on the outgoing link of its IDNX using virtual circuit switching and a proprietary frame format. It has a limited dynamic bandwidth allocation capability. The next chapter provides the methodology used to test the suitability of porting one of the aforementioned dynamic bandwidth allocation algorithms proposed for ATM to a TDM platform such as the IDNX.

III. Methodology

This chapter describes the methodology used to test the system. It first defines the system boundaries and services. The metrics collected, parameters and factors considered, and workload submitted are discussed next. Finally, the experimental design is described.

3.1 System Boundaries

The system under test (SUT) is the time-division multiplexer, including the incoming user circuits and outgoing aggregate link. Details about the operation of each circuit coming into the multiplexer will not be considered. Instead, circuits will be seen as simply a "class" of traffic and will be assumed to arrive in a common framing format. The aggregate link will be used to determine the utilization of the outgoing link and as a "finish line" for the frame to calculate queuing delay. Consequently, whether frames leaving the multiplexer are delivered successfully or not is not measured — only that frames were sent.

The component under test (CUT) is the bandwidth manager inside the multiplexer. For the baseline system, this is represented as an empty box with zero delay. For the dynamic allocation system, the CUT is the set of components added to the standard multiplexer that dynamically allocate bandwidth to the circuits. Figure 3.1 depicts the system to be tested.

3.2 System Services

In its simplest form, the SUT takes defined user circuits, such as a voice circuit, LAN circuit, and VTC circuit, multiplexes them together, and forwards them to their destination via a virtual circuit at a specified rate. Using Dynamic Bandwidth Allocation (DBA), the same service is performed, but the rate at which frames are forwarded is updated periodically based on demand — an additional service.

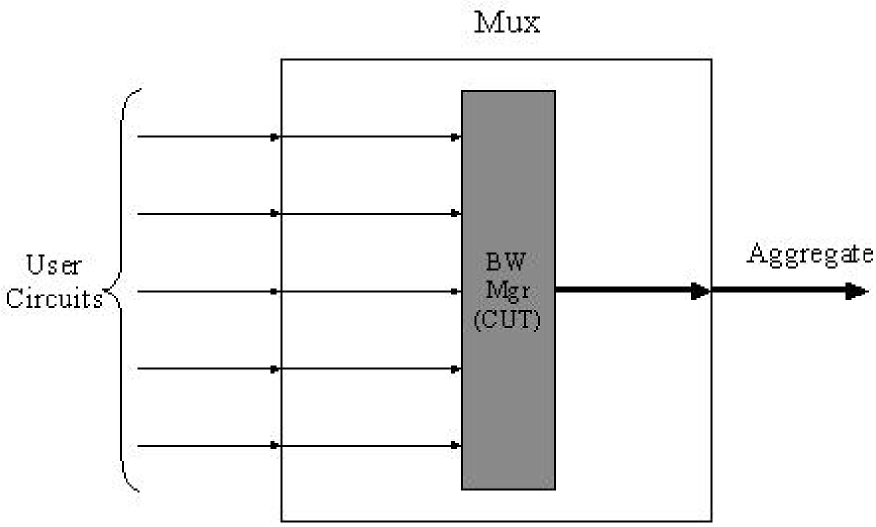

Figure 3.1. System Under Test

The system's potential outcomes include:

- Frame Outcomes
  - A frame traverses the system successfully
  - A frame is dropped due to buffer overrun
  - A frame is dropped for some other reason
- DBA Outcomes
  - The circuit with the highest utilization is given an increased bandwidth allocation by the bandwidth manager (sufficient residual bandwidth exists to reallocate)
  - The circuit with the highest utilization is denied a bandwidth increase
  - A circuit's request for increased bandwidth is denied by the bandwidth manager even though enough bandwidth is available

3.3 Performance Metrics

This research shows whether DBA will more efficiently utilize the total bandwidth allocated to a communications site. Consequently, the primary metric is utilization on the aggregate link. Additionally, even though delay can be tolerated by data traffic, excessive delay will result in poor quality in voice or video traffic on the receiving end. Therefore, queuing delay is also measured. In this document, queuing delay is defined as the time from which a frame arrives at the multiplexer and inserted into the input buffer to the time that the frame is extracted from the buffer. It does not include time necessary to service the frame. These two metrics are the only metrics considered.

3.4 Parameters

The term "parameter" refers to anything that can affect system performance [Jai91]. The following paragraphs describe the system and workload parameters.

3.4.1 System Parameters. A system parameter is something inherent in the system that affects performance. Typically, system parameters can vary from system to system, but are fixed within a given system [Jai91]. The following paragraphs describe the system parameters for the system identified in Section 3.1.

3.4.1.1 Bandwidth Allocation Granularity. Each circuit is allocated a specific bandwidth. However, the allocation cannot be completely arbitrary. All multiplexers have a granularity, or fixed increment, at which bandwidth can be allocated. For example, the multiplexer might require individual circuit bandwidths be allocated in increments of 32 kbps. In addition to restrictions imposed on the granularity of bandwidth allocated to individual circuits, there are usually similar restrictions on the aggregate link, but they are typically larger. Due to necessary overhead for particular circuits, the total bandwidth required for each circuit may not fall exactly on a granularity boundary. Consequently, there may be residual bandwidth in a circuit that is unusable because it falls below the allocation granularity. In a multiplexer employing DBA, this can obviously limit utilization increases. From a theoretical standpoint, if the multiplexer could allocate bandwidth in granularities of bits per second, then utilization increases would be much larger than with granularities of 32 kbps.

3.4.1.2 Maximum Supported Aggregate Bandwidth. Each multiplexer has a maximum speed with which it can send frames to their destination. Additionally, the aggregate allocation is the sum of the individual circuit allocations. Therefore, the sum of these allocations cannot exceed the multiplexer's maximum supported bandwidth. This parameter can affect performance if the multiplexer is supporting a large number of circuits requiring high bandwidths. Either the multiplexer would not be able to support the number of desired circuits, or bandwidth for some or all circuits would suffer. Typically, this is rarely a problem. Assuming that the user has a multiplexer sized appropriate to his mission, most modern multiplexers support maximum aggregate bandwidths far beyond their needs. This is even less of a problem in tactical networks since bandwidth allocations over a satellite are much smaller than typical multiplexer capacities.

3.4.1.3 Multiplexing Speed. Multiplexers have latencies associated with them — the time from which a frame enters the multiplexer to the time it leaves the multiplexer on its way to its destination. This delay is due mostly to the length of time cells must wait in the input queue, but the time it takes a cell to physically propagate through the multiplexer's circuitry and the time it takes the bandwidth manager to make a decision (see below) are also included. This parameter can affect performance of time-sensitive traffic (e.g., voice, video), potentially resulting in the multiplexer dropping frames if the time is excessive.

3.4.1.4 Bandwidth Management Speed. If a multiplexer employs DBA, then there is some time associated with deciding whether to reallocate bandwidth or not. Excessive delay in this area can result in either unacceptable loss or delay, depending upon the implementation. As mentioned in Section 3.3, though, there are a few problems with modeling this parameter. First, some bandwidth managers are so integrated into the functionality of the multiplexer that it is difficult or impossible to separate what delay is caused by the bandwidth manager versus the overall delay of the multiplexer. Second, some bandwidth managers are invoked at regular intervals while others are invoked based on a circuit's request. Therefore, it would be difficult to compare the delay caused by the bandwidth manager. Since bandwidth managers must minimize the reallocation decision to prevent excessive delay, this value should be small compared to queuing delay [SCY98, Shi98]. This study assumes a negligible delay due to the reallocation decision.

3.4.1.5 Input Queue Size. The number of frames in the input queue awaiting service can also affect performance. Obviously, the more frames awaiting service there are the longer it will take to be served. This can present a problem regardless of the multiplexer's implementation. From a theoretical perspective, even if the queue was infinite and the arrival rate was higher than the service rate for a sustained period of time a delay would result. Conversely, if the queue size were fixed such that the largest number of frames in the queue was small enough to prevent noticeable delay or loss, then newly arriving frames could be dropped when the queue filled up. Generally speaking, however, multiplexers are designed so that this problem is minimized.

3.4.1.6 Reallocation Methods. There are two basic methods for reallocating bandwidth dynamically — each of which produces different results and side effects. The first method is *incremental reallocation.* Incremental reallocation steps a circuit's bandwidth up or down in increments of the system's granularity or the circuit's minimum allocation size, whichever is greater. For instance, if the system allocates bandwidth in blocks of 8 kbps, when bandwidth is reallocated to other circuits, it is allocated in increments of 8 kbps. In the case of a voice circuit, however, in which a call must be established at, say, 32 kbps, bandwidth is reallocated in increments of 32 kbps even though the system's granularity was 8 kbps. This method prevents drastic drops in a circuit's allocation for only a single period of low utilization. However, the expected utilization gain using DBA would be much lower than using wholesale reallocation.

In *wholesale reallocation*, all available bandwidth is reallocated to the most utilized circuit, perhaps up to a specified maximum. For instance, if a circuit is allocated 32 kbps and fully utilized, and another circuit has 16 kbps of unused bandwidth, the entire 16 kbps can be allocated to the first circuit at once. Conversely to incremental reallocation, the expected utilization gain would be much larger with wholesale allocation. Similarly, drastic drops in a circuit's allocation for only a short period of low utilization could cause some performance degradation due to deallocation and subsequent reallocation.

3.4.1.7 Monitoring Period Length. In a DBA algorithm that uses a monitoring period to monitor system utilization, such as that suggested in [SCY98], the monitoring period length can affect queuing delay. For example, suppose that the monitoring period is long to obtain a more accurate picture of the system utilization over time. Bandwidth is only adjusted at the end of a monitoring period, so queue size could increase significantly if a very lightly loaded circuit suddenly becomes heavily loaded. Larger queue sizes translate directly into longer queuing delays.

3.4.1.8 Length of Time-Out Period Prior to Reset. When allocating bandwidth dynamically, it occasionally becomes necessary to reset the bandwidth allocations to their original setting. Such is the case when all circuits are at 100% utilization but their bandwidths are not at their originally assigned peak rates. Thus a reset is needed in order to prevent input queues from overflowing due to a higher arrival rate than service rate. However, deallocating bandwidth to a circuit instantaneously could mean buffer overflow for that circuit and/or lost frames. A time-out period may be employed during which the circuit being deallocated is notified to reduce its frame generation rate. At the end of that period, the reset would occur. However, adding a time-out period prolongs the time before bandwidth can be adjusted to appropriate levels resulting in larger queue sizes and longer queuing delays.

3.4.1.9 Frame Size. For a fixed transmission rate, frame size affects average queue size and delay. For example, at a given transmission rate a 512-byte frame spends approximately ten times longer in service than a 53-byte frame. Longer service times translate into longer waiting times (i.e., queuing delays). Thus, smaller frame sizes tend to produce shorter queuing delays while larger frame sizes tend to produce longer queuing delays.

3.4.2 Workload Parameters. A workload parameter is a characteristic of user demands on the system that affects performance. Workload parameters vary from installation to installation and from user to user [Jai91]. The following paragraphs describe the workload parameters for the system.

3.4.2.1 Offered Load from User Circuits. The rate at which frames arrive at the multiplexer from the user circuits can have a significant impact on the aggregate utilization. For instance, due to the bursty nature of data traffic, the performance of the bandwidth manager will have little effect on the aggregate utilization of data circuits. If some of the data circuits are inactive, it will be impossible to achieve 100% utilization. Similarly, if all of the user circuits are constant-use full-motion video circuits, then the aggregate bandwidth will always be at or near 100%. As with the data circuit scenario, though, the overall aggregate utilization had little to do with the bandwidth manager and more to do with the type of traffic on and utilization of the user circuits. These two scenarios are extreme cases, but the point is made. The real impact of the bandwidth manager is made when utilization of user circuits is random and the bandwidth manager is juggling different classes of traffic.

3.4.2.2 Distribution of Traffic Classes. Consider the scenarios outlined in the preceding paragraph. If all circuits are data circuits (i.e., ABR traffic), then queuing delay will tend to be low. Because of the bursty nature of data traffic, statistically, the probability that the input queue will fill is low and delivery is guaranteed. If all circuits contain CBR traffic, though, the queuing delay could be much higher since the multiplexer must deal with a constant stream of cells. Thus, the service rate would have to be greater than or equal to the arrival rate in this situation. Consequently, the distribution of traffic classes across the user circuits can affect the multiplexer's queuing delay.

3.5 Factors

Factors are a subset of the parameters and are those parameters that are varied in the experiments [Jai91]. The remaining parameters remain constant. The following paragraphs list the factors for this study and the values that each take on.

3.5.1 System Factors.

3.5.1.1 Bandwidth Allocation Granularity. The size of the chunks that the multiplexer can allocate to circuits impact the bandwidth manager's flexibility to dynamically allocate bandwidth and, thus, aggregate utilization. The smaller the granularity of allocation, the greater the aggregate utilization should be. The levels chosen for this study are as follows:

- 8 kbps
- 32 kbps

- 64 kbps

The first two levels represent typical granularities of multiplexers and are far enough apart to show whether this factor does, in fact, affect aggregate utilization. The last is a more extreme case to determine how significantly granularity can actually impact aggregate utilization.

3.5.1.2 Length of Monitoring Period. Like the length of the time-out period, the length of the monitoring period prior to reallocation can affect queuing delay. However, the magnitude of the effect is not known. Therefore, the following levels were chosen:

- 5.0 seconds
- 10.0 seconds
- 50.0 seconds

The first two levels should show the effect of a small difference in monitoring period, while the last should show the effect of a long monitoring period. These levels were chosen much smaller than that recommended in [SCY98] based on results from system pilot runs.

3.5.2 Workload Factor — Offered Load from User Circuits. The inter-arrival time from the circuits entering the multiplexer can have a significant impact on the aggregate utilization. If the inter-arrival time is large on all of the user circuits, then the aggregate utilization will be low. The converse is also true. This study shows that aggregate utilization can be increased if unused bandwidth is available to other circuits currently in use. The levels to be used in the study are as follows:

- System underload
- Data overload
- Voice overload

- Voice and data overload

The system underload workload is defined as one in which all circuits submit a very low offered load. The three types of overload conditions are defined such that one or more circuits submit a high offered load and the remaining circuits submit a very low offered load. For example, the data overload workload consists of a high offered load submitted by the data circuits and the lower underload workload submitted by the voice and video circuits. The DBA algorithm should not affect utilization much in the underload condition, but could make a significant difference during the various overload conditions. The chosen levels provide an appropriate exercise of the system under the various conditions. Additionally, once results have been obtained using these offered loads, the SBA system and best DBA configuration will submit a set of extreme offered loads in order to compare performance with the more realistic offered loads.

3.6 Evaluation Technique

Simulation is the primary evaluation technique. Models were generated and simulated using OPNET Modeler 8.0 — a robust and powerful network modeling package [OPN01]. Additionally, because the static allocation model conforms to classical Time-Division Multiplexing and the dynamic model can be broken down into a series of static allocations, theoretical queuing models were used to validate the results of the simulations.

3.7 Workload

In order to fully evaluate the effects of the various factors on the aggregate utilization and queuing delay, separate workloads were created for every combination of workload factors given above. The following paragraphs give the application services and associated parameter values.

3.7.1 *Offered Load.*

3.7.1.1 *Data Circuits.*

Data Circuits are modeled using a series of ON/OFF sources, one for each application service. On and off periods are exponentially distributed with mean outcomes based on loading level. Data circuit loading levels are defined in Tables 3.1 and 3.2. In these tables, the inter-arrival and inter-request time parameters define the off period. The size parameter determines the on period, based on the circuit's assigned data rate. For example, an 8 kB transaction would take 2 seconds to transmit on a circuit having a 32768 bps line speed. The loading levels were chosen to represent realistic size and inter-request times for common data applications under moderate and heavy loading.

Table 3.1. Underload Definition for Data Circuits

Data Application	**Parameters**	**Mean Values**
Web browsing	Page inter-arrival time Size	5 sec 32 kB
E-mail	Send/Receive inter-arrival time Size	5 sec 16 kB
FTP sessions (file download)	Inter-request time Size	30 sec 128 kB
Database access	Inter-arrival time Size	5 sec 8 kB
Offered Load Normalized to Circuit Data Rate		46.5%

Table 3.2. Overload Definition for Data Circuits

Data Application	**Parameters**	**Mean Values**
Web browsing	Page inter-arrival time Size	0.5 sec 64 kB
E-mail	Send/Receive inter-arrival time Size	1 sec 64 kB
FTP sessions (file download)	Inter-request time Size	30 sec 1024 kB
Database access	Inter-arrival time Size	0.5 sec 32 kB
Offered Load Normalized to Circuit Data Rate		93.7%

3.7.1.2 Voice Circuits. Voice circuit loading is represented by the number of possible simultaneous conversations that can be in progress. Each conversation uses 32768 bps of bandwidth, so the number of simultaneous conversations for an underload workload is 4, and for an overload workload, 8. Talk spurts and silence periods are represented as ON/OFF sources with exponentially-distributed periods [CPR96]. Tables 3.3 and 3.4 define the loading levels for the voice circuit. Therefore, if the number of simultaneous conversations is at the maximum of 8, the highest offered load on this circuit will be 42.6% as shown in Table 3.4.

Table 3.3. Underload Definition for Voice Circuit

Parameter	**Mean Value**
Mean silence length	1.35 sec
Mean talk spurt	1 sec
Switched voice circuit data rate	131072 bps
Offered Load Normalized to Circuit Data Rate	21.3%

Table 3.4. Overload Definition for Voice Circuit

Parameter	**Mean Value**
Mean silence length	1.35 sec
Mean talk spurt	1 sec
Switched voice circuit data rate	262144 bps
Offered Load Normalized to Circuit Data Rate	42.6%

3.7.1.3 Video Circuits. Call inter-arrival times and mean call lengths are represented as ON/OFF sources with exponentially-distributed periods. The video circuit's offered load under all loading conditions are defined in Table 3.5. For simulation efficiency, the mean call length and inter-arrival time are much shorter than that specified in Chapter 1, but the normalized offered load of 7.7% is the same.

3.7.2 Distribution of Traffic Classes. Traffic classes are modeled differently depending on the class of traffic. Data traffic inter-arrival rate is modeled using an

Table 3.5. Workload Definition for Video Circuit

Parameter	**Mean Value**
Call inter-arrival time	1 hour
Mean call length	5 min
Video circuit data rate	262144 bps
Offered Load Normalized to Circuit Data Rate	7.7%

exponential inter-arrival distribution. Voice and video traffic use a constant arrival rate. The parameters vary according to the inter-arrival configurations specified above.

3.8 Experimental Design

3.8.1 Type. Correlation among selected factors was not readily known or apparent. Therefore, a full factorial design was used. One DBA algorithm was implemented — Instantaneous VP Utilization Measurement [SCY98]. This algorithm was selected because of its simplicity — calculating instantaneous utilization via a frame count — the reallocation decision should be fast, resulting in negligible increases in queuing delay. Furthermore, because the algorithm can be completely implemented in software, it lends itself to other platforms, including TDM. The Intelligent Multiplexing algorithm [Hoe94] was not chosen because it requires that the multiplexer distinguish between traffic classes. Many TDM platforms do not support this. Calculation complexity precluded selection of the Adaptive Bandwidth Demand Estimation algorithm [Shi98]. Such complexity might result in excessive time for a reallocation decision. The VP Bandwidth Control algorithm [Sai97] is very similar to the selected algorithm. However, the VP Bandwidth Control algorithm relies on only the current and previous measurement; the selected algorithm relies on the current measurement and all past measurements. Therefore, though the two algorithms are very similar, the selected algorithm should perform better. The selected algorithm's performance was compared with a static allocation method.

This results in 40 experiments without regard for replications. The response variables are aggregate utilization and queuing delay. Refer to Section 3.3 for detailed information.

3.8.2 Replications. The central hypothesis of this study is that dynamic bandwidth allocation on a time-division multiplexer can achieve higher utilization on its aggregate link than static allocation, without adversely affecting queuing delay. The data should show with 90% confidence that the DBA algorithm is better than the static allocation method. Specifically, the DBA system utilizations should be statistically higher than the static system. Conversely, the DBA system's queuing delays should be either statistically equivalent or only slightly higher.

The number of observations taken per configuration to achieve a 90% confidence depends upon the outcome variance. The utilization variance was quite low since time-division multiplexers are designed such that a particular offered load produces an equivalent aggregate utilization. Therefore, the number of replications needed was low. Assuming the number of experiments run was five, and the standard deviations are both two, the difference between the utilizations only need be greater than 2.29% to be statistically different at 90% confidence. The queuing delay variance should also be low, so a similar derivation can be made for it. Of course, if the data variance turns out to be higher than assumed, then more experiments need to be run to achieve the same 90% confidence. Similarly, if the difference in utilization (or queuing delay) is less (or more) than 2.29%, then more experiments will need to be run in order to achieve the same 90% confidence. The total number of experiments to be run is 200.

3.8.3 Experimental Error. The predictor models for the performance of each system are the means of the two metrics collected — aggregate utilization and queuing delay. This model is based on several assumptions [Jai91]:

- Model errors are statistically independent
- Errors are normally distributed with zero mean
- Error standard deviation is constant

Consequently, for models to be valid, these assumptions must be verified. Therefore, each assumption was verified using techniques discussed in [Jai91]. Had one or more of these assumptions not held, then more system analysis would be needed to determine what other parameters needed to be modeled.

3.9 Chapter Summary

This chapter described the bounds of the system under test including services provided and possible responses. It also enumerated the parameters associated with the system and the workload to be submitted. From that list of parameters, allocation granularity, monitoring period, and offered load were the chosen factors. The performance metrics chosen to measure the effect of these factors were aggregate utilization and queuing delay. Finally, a full factorial experimental design was chosen using simulation as an evaluation technique, resulting in a total of 40 simulations.

IV. Results and Analysis

This chapter presents the results from simulations described in Chapter 3. First, an overview of the system design and configuration is given. The simulation results are then presented with pertinent analysis of those results.

4.1 System Design

The dynamic bandwidth allocation (DBA) model implemented is an enhancement of that developed by Shiomoto, et al. [SCY98]. Their research assumes homogeneous switched ATM circuits. This study modifies that model to support heterogeneous permanent circuits in a TDM environment. Because the system accepts heterogeneous circuits, each circuit's instantaneous utilization is calculated separately. Instantaneous utilization is calculated using

$$\rho_i = \alpha_i n_i(t) + (1 - \alpha_i)\rho_i(t - \Delta) \tag{4.1}$$

$$\alpha_i = \frac{-2(1-K) + \sqrt{4\,(1-K)^2 + 8\,(\varepsilon^{-1}-1)\,(1-K)}}{2\,(\varepsilon^{-1}-1)} \tag{4.2}$$

$$K = \cos\left(2\pi \frac{slotFreq_i}{TotalSlots}\right) \tag{4.3}$$

where $n_i(t)$ is the number of frames arriving on circuit i during the last time slot, ρ_i(t-Δ) is the last computed utilization for circuit i, α_i is the weighting factor of the ith circuit, and ε is the objective frame loss rate.

Two changes are made to Shiomoto's equations for calculating instantaneous utilization and the weighting factor, α (2.7) and (2.10), respectively. First, the instantaneous utilization is determined for each circuit. Second, the peak frame rate is changed to a measure of the number of time slots per second currently assigned to the circuit ($slotFreq_i$). Similarly, the aggregate link transmission time is changed to the total number of time slots per second (*TotalSlots*). The algorithm is also modified to support permanent circuits rather than switched circuits to support tactical military communications networks. To support permanent circuits, residual bandwidth is allocated to the circuit with the highest demand rather than using the residual bandwidth as the basis for an admission decision.

Figure 4.1 shows the DBA state-transition diagram for the algorithm developed. After initialization, the first time slot begins service in the *svc_start* state. The process then transitions to the *idle* state. If an arrival occurs, an interrupt is generated, forcing the process to the *arrival* state. This state places the arriving frame in the appropriate circuit's input buffer, then transitions the system back to the *idle* state. At the end of each time slot, an interrupt is generated forcing the system to the *svc_compl* state, which calculates the queuing delay. The process then transitions to the *upd_lambda* state, which calculates the instantaneous utilization of each circuit. Next, the process returns to the *svc_start* state to begin servicing another frame and finally back to the *idle* state. At the end of the monitoring period, another interrupt is generated. This interrupt forces the system to the *update_BW* state. This state reallocates all unused time slots (down to a specified minimum) from the circuit with the lowest utilization to the one with the highest utilization. Finally, in the event that all circuits are utilizing all of their time slots, but those slot assignments are not the initially-assigned rates, an interrupt for the *reset* state is generated. This state resets the time slot allocations to the original assignments.

4.2 System Configuration

Figure 4.2 depicts the configuration of the system under test. The system consisted of four user circuits — a voice circuit, a video circuit, and two data circuits (labeled NIPRNET and SIPRNET). Based on typical data rates allocated to deployed sites, these circuits were assigned data rates of 262144 bps, 262144 bps,

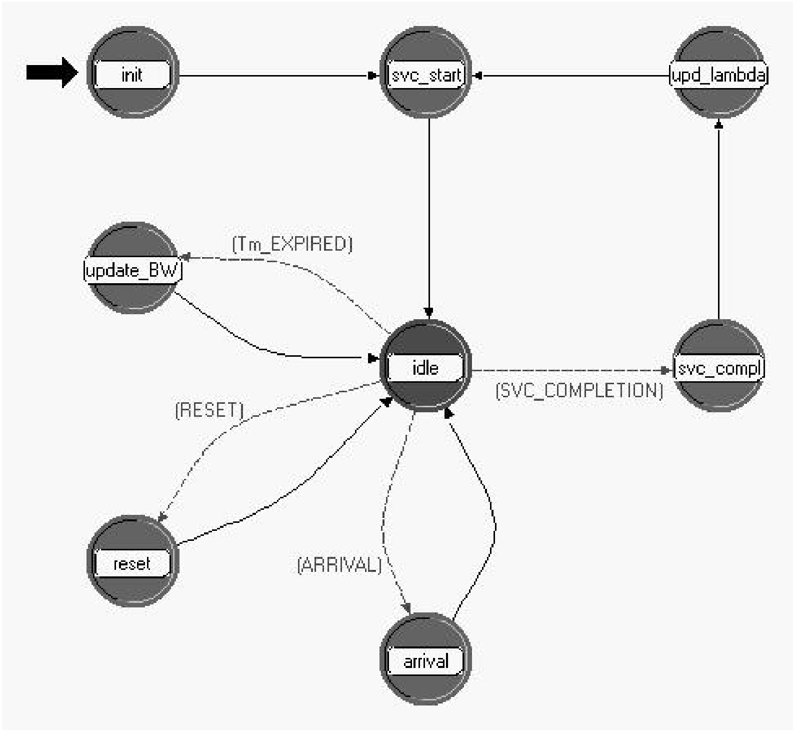

Figure 4.1. Dynamic Bandwidth Allocation State Transition Diagram

131072 bps, and 131072 bps, respectively. The aggregate bandwidth was 786432 bps. The model also assumed a fixed frame size of 4096 bits, a minimum circuit data rate of 8192 bps (32768 bps for the voice circuit), and a maximum frame loss rate of 1E-4.

The interarrival times for all workloads submitted to the static model and the All Circuits Underload workload submitted to the dynamic model remained the same; they did not change during the course of the simulation. To test the effectiveness of the DBA algorithm, however, these times were reduced on the three overload workload conditions submitted to the dynamic model. For example, if a circuit was using all of its allocation and was subsequently granted a greater allocation, the inter-arrival time was decreased to take full advantage of the new allocation. Had this not been done, no change would have been seen in the system utilization thus creating an inaccurate picture of the effectiveness of the algorithm. However, this

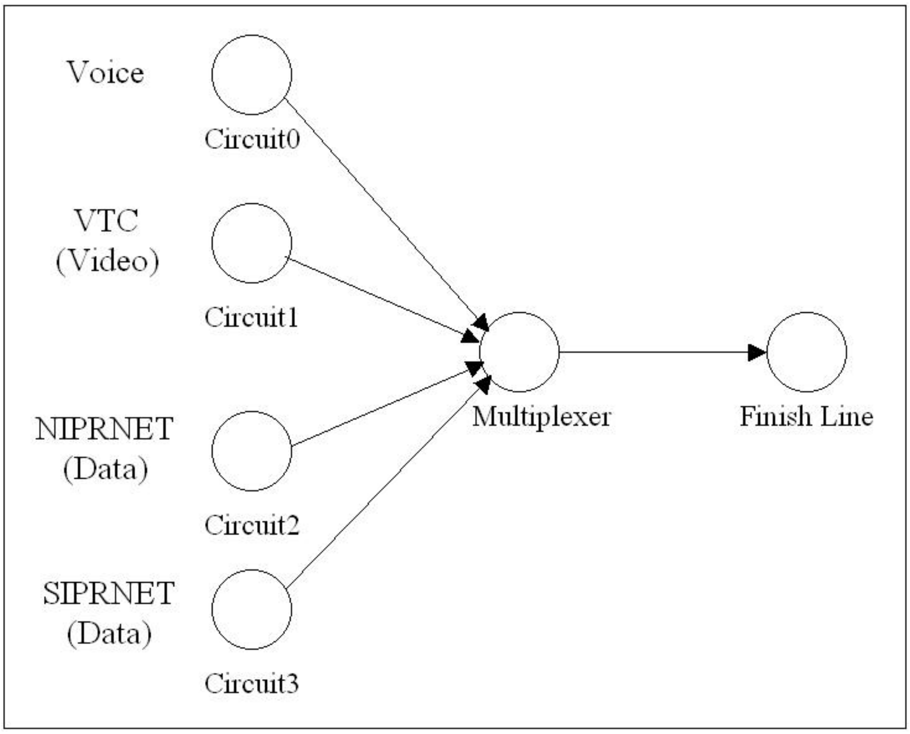

Figure 4.2. System Under Test

change was not made to the System Underload workload submitted to the dynamic model because this scenario was not meant to stress the system.

4.3 Model Verification and Validation

The validation process ensures the created system or derived model accurately models some known system such as a theoretical model. The verification process ensures the derived model is implemented correctly [Jai91]. For example, for a simulation model, validation ensures the algorithm correctly models the system and verification ensures the model is defect-free.

To evaluate the model's behavior sufficiently, several scenarios were simulated on both the static and dynamic models. Additionally, workloads and system parameters were chosen such that the theoretical analysis was simplified. First, the number of circuits was varied between one, two, and five to verify the model could operate correctly under a varying number of inputs, including the degenerate case of one. Second, the ON/OFF periods were equal and constant. Figure 4.3 shows the workload submitted to the two-circuit configuration using the static allocation method. As the figure shows, Circuit 0 was set to start transmission first; Circuit 1 then began transmitting at the same data rate 600 seconds later. Both sources then ceased transmission simultaneously. This setup allowed easy validation that the instantaneous queuing delays for each circuit and aggregate utilization were as expected. In this configuration, one would expect the instantaneous utilization to be 50% when only one circuit was active and 100% when both were active. Figure 4.4 confirms these results. Figure 4.5 shows that the queuing delay for both circuits is 437.5 ms, which also matches the theoretical model. In all configurations, the utilization and queuing delay results matched that of the theoretical model. Refer to Appendix A for a more detailed analysis of the static model's verification and validation.

Figure 4.6 depicts an overload-type workload submitted to the two-circuit configuration using the dynamic model. Initially, the workloads submitted were the same for both circuits — 16384 bps each. However, because Circuit 0 is currently the only one transmitting, it is able to take advantage of part of Circuit 1's unused bandwidth. The bandwidth manager allocates all of Circuit 1's unused bandwidth down to an 8192 bps threshold. This gives Circuit 0 a new bandwidth of 24576 bps, which it takes advantage of. Circuit 0's bandwidth then decreases to the originally assigned data rate 600 seconds later when Circuit 1 begins transmitting. Once again, this setup allowed easy validation that the instantaneous queuing delays for each circuit and aggregate utilization were as expected. It also validated that the DBA algorithm was functioning properly. In this configuration, one would expect the instantaneous utilization to be 75% when only one circuit was active and 100% when both were active. Figure 4.7 confirms these results. Just like the static model, the simulation results from every configuration unanimously matched that of the

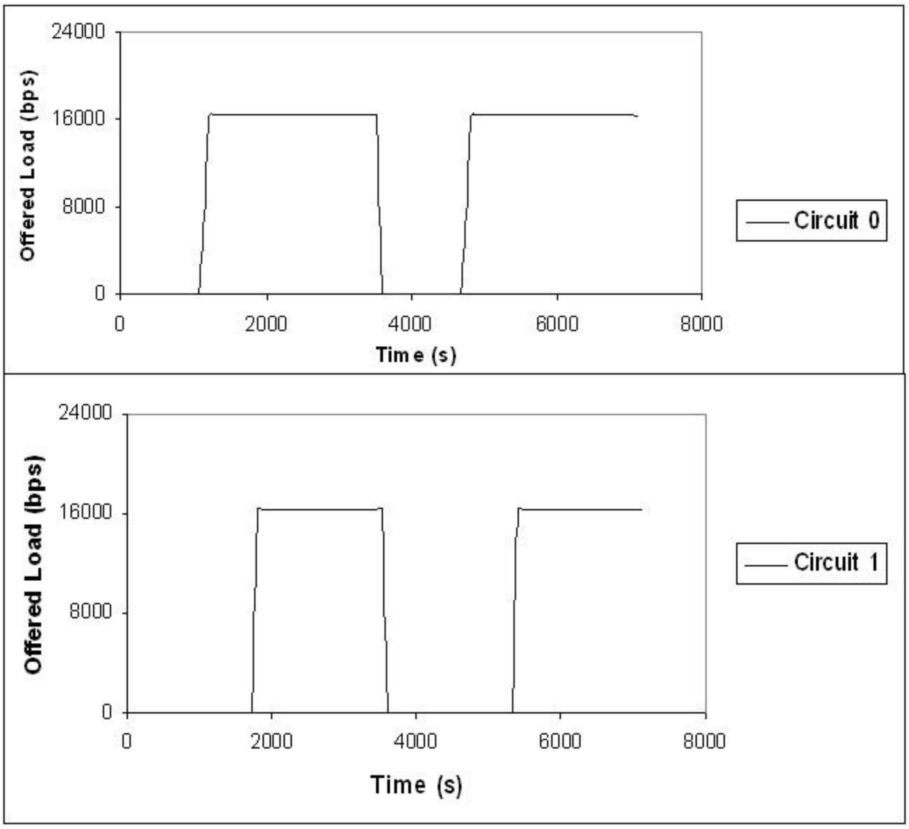

Figure 4.3. Verification and Validation Workload Submission for the Static Model

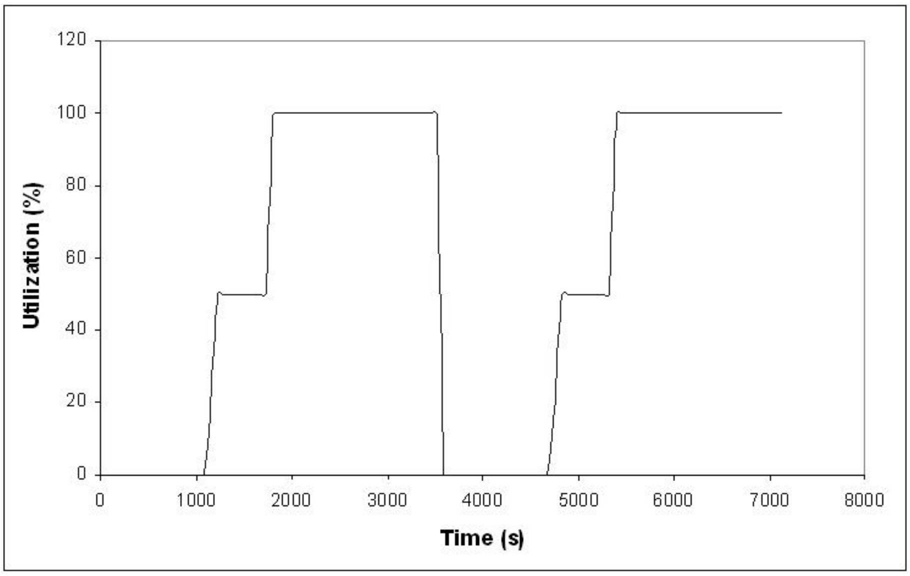

Figure 4.4. Utilization for Two-Circuit Configuration Using the Static Model

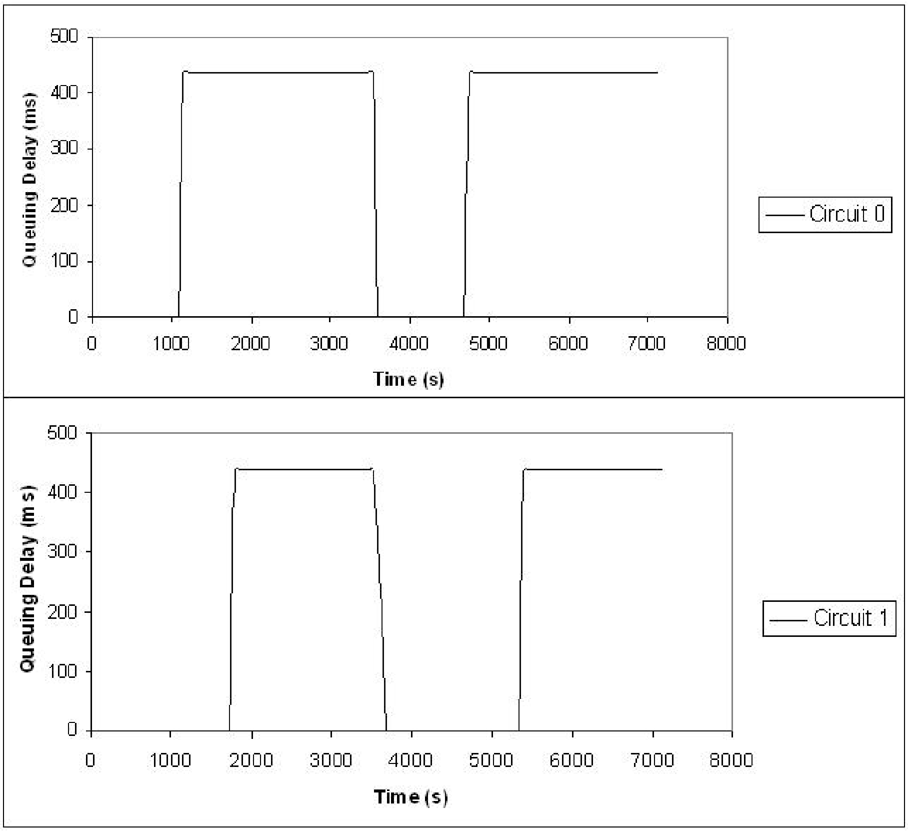

Figure 4.5. Queuing Delay for Two-Circuit Configuration Using the Static Model

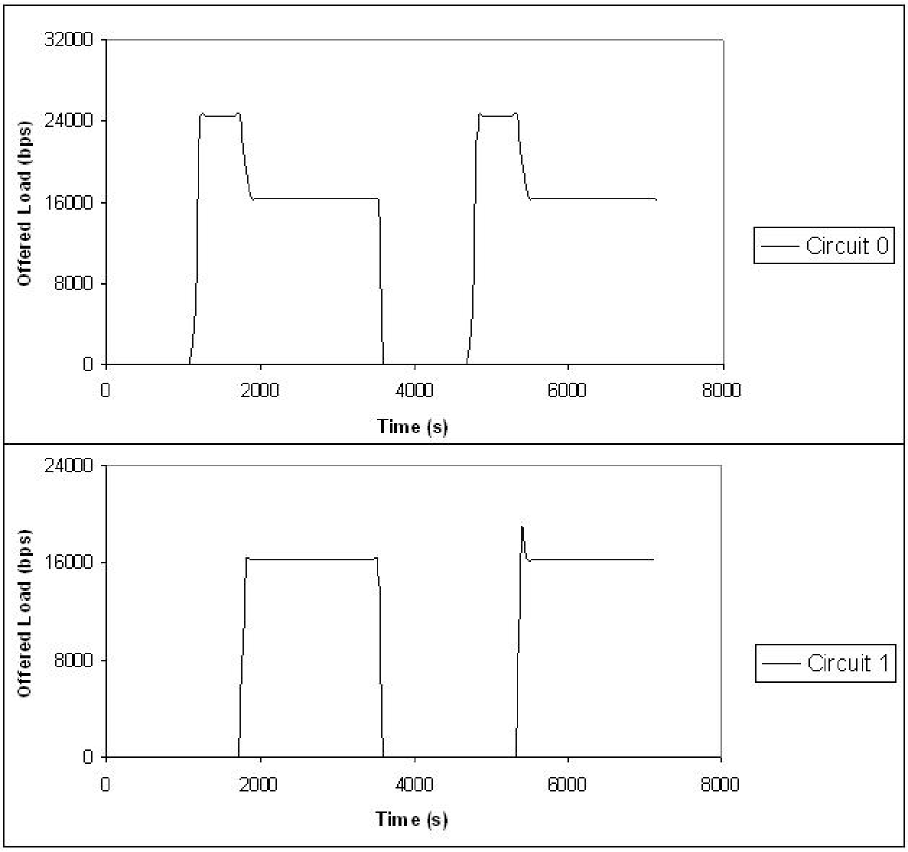

Figure 4.6. Verification and Validation Workload Submission for the Dynamic Model

theoretical model for utilization. Theoretical modeling indicates that the queuing delay for Circuit 0 should be 354 ms when it is the only circuit active. When both circuits are active, queuing delays should be 437.5 ms — the same as in the static allocation model. In practice, however, this is not possible since the theoretical model assumes that the DBA algorithm's monitoring period is zero. If a circuit becomes active during the monitoring period, however, queue sizes and, thus, queuing delays will increase linearly. Therefore, as Figure 4.8 indicates, observed queuing delays matched the theoretical model when one circuit was active and were much higher than the theoretical model when both circuits were active. Refer to Appendix A for a more detailed analysis of the system's verification and validation.

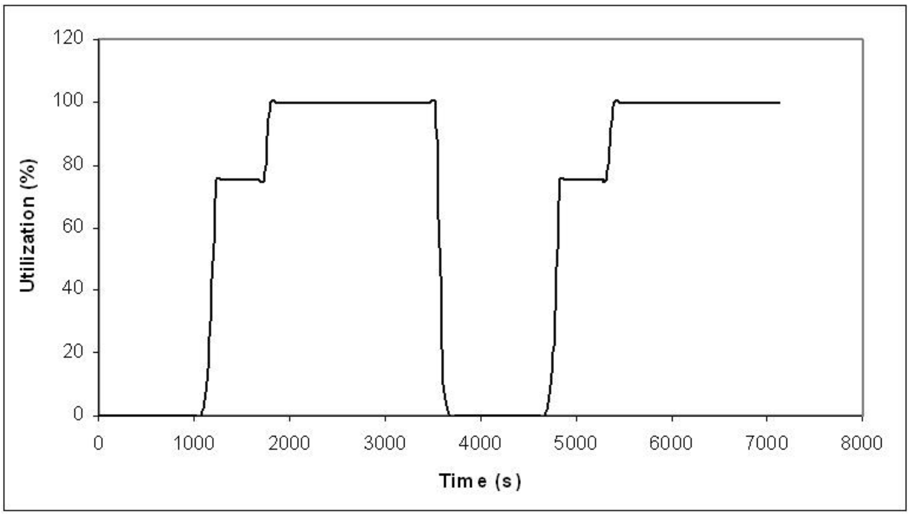

Figure 4.7. Utilization for Two-Circuit Configuration Using the Dynamic Model

Finally, both models were tested again using the same setup as before with the exception of the ON/OFF period distributions. These periods' distributions were changed from constant to exponential to see if the results were similar. In all cases, the workloads produced similar utilizations. Queuing delays on the DBA system were more extreme than that experienced using the constant distribution but this was expected. Since one circuit would tend to be active more than the others and all would remain active together for a period, the system needed time to adjust the bandwidth accordingly. If all circuits were transmitting at their originally-assigned peak rates, however, there would be no way for the other circuits to reduce the frame backlog which had developed while the algorithm was adjusting. This issue will be discussed later in this chapter.

4.4 Static Allocation vs. Dynamic Allocation — First Iteration

4.4.1 Utilization. Results were obtained comparing the static system to the dynamic system using the DBA algorithm outlined in Section 4.1 (referred to as DBA-1). Figure 4.9 compares the mean utilizations of the DBA-1 system to the static system. The DBA-1 utilizations represent the mean across both factors for a

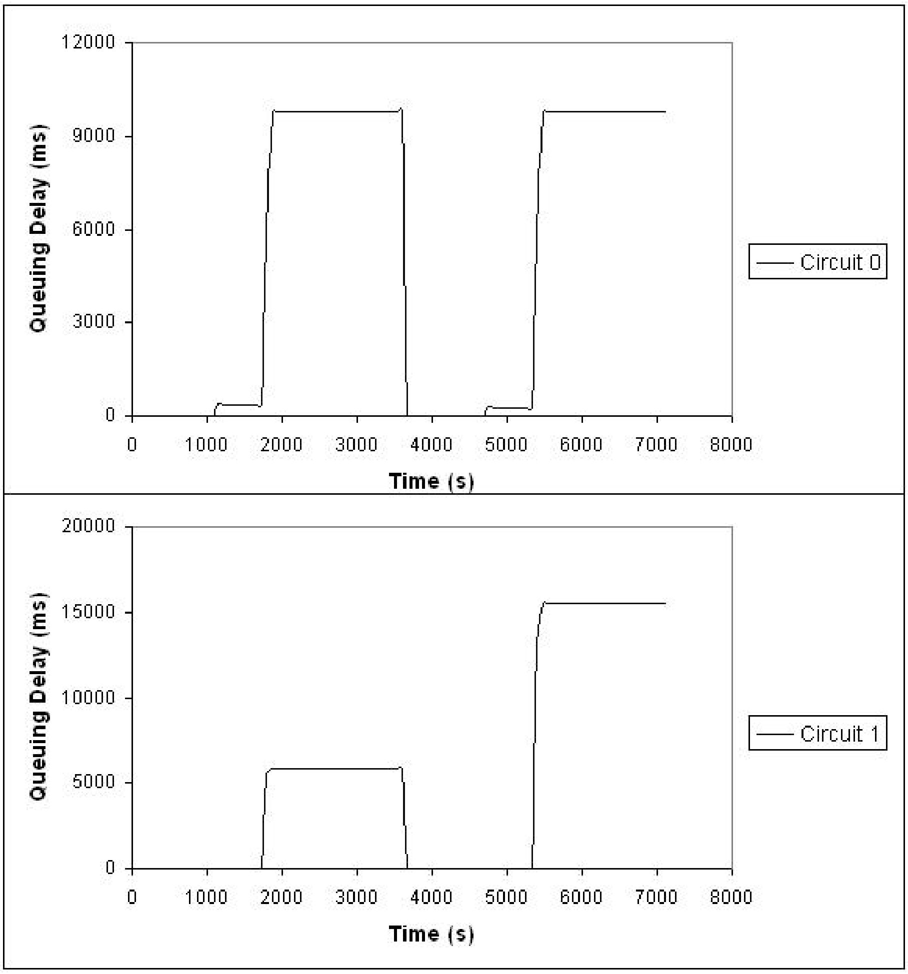

Figure 4.8. Queuing Delay for Two-Circuit Configuration Using the Dynamic Model

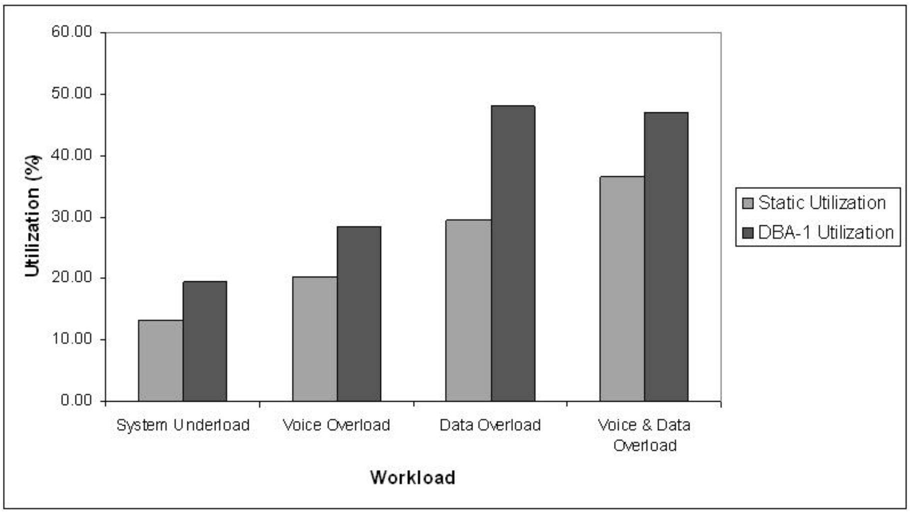

Figure 4.9. Utilization: Static Allocation vs. DBA-1

particular offered load. Every DBA-1 configuration produced statistically significant utilization gains over the static system at 90% confidence. Refer to Table 4.1 for the confidence intervals on the utilization gains. The smallest average gain observed was 6.24% with the System Underload workload. This gain indicates that even in light loading, the system is still able to optimize the available bandwidth. The largest average gain observed was 18.48% with the Data Overload workload. The system performed better with the Data Overload workload than the Voice and Data Overload workload because the bandwidth manager was able to optimize bandwidth allocation for the data circuits with only two circuits heavily loaded. However, with the Voice and Data Overload workload, three of the four circuits were heavily loaded causing the bandwidth manager to juggle between the three circuits competing for additional bandwidth. Nevertheless, the bandwidth manager was able to increase aggregate utilization under all four workloads by allowing circuits with a high demand to claim unused bandwidth from circuits with a lower demand. This effect enhances system performance so long as delay does not increase beyond acceptable limits for real-time traffic.

Table 4.1. Utilization Gain 90% Confidence Intervals

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Workload	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**
System Underload	4.98 7.54	5.05 7.25	4.96 7.52	4.98 7.54	4.98 7.54	4.98 7.53	4.98 7.54	4.98 7.54	4.98 7.54
Data Overload	19.43 20.71	18.88 19.47	17.35 19.27	19.44 21.06	18.45 19.68	17.61 19.27	17.23 18.72	16.14 17.66	15.46 16.86
Voice Overload	8.89 9.47	7.75 8.73	7.55 7.96	9.07 10.61	7.40 9.02	7.02 7.73	7.47 8.12	6.73 7.93	6.57 7.39
Voice & Data Overload	10.34 11.16	9.73 10.16	10.80 11.76	10.38 11.55	9.76 10.79	11.05 11.81	9.03 10.77	8.67 10.21	9.75 10.56

Workload accounted for 99.16% of the observed variation in the data. There was some observed variation attributable to the monitoring period and allocation granularity factors, but statistically this variation was negligible. The unexplained variation accounted for 0.37% of the observed variation. Therefore, it was concluded that neither the monitoring period nor the allocation granularity had an effect on the DBA-1 system's utilization. This was expected since a time-division multiplexer is designed to produce the same level of output as it is offered so long as the input buffers don't overflow.

4.4.2 Queuing Delay.

4.4.2.1 Data Circuits. As Figures 4.10 through 4.13 and 4.14 through 4.17 show, both the NIPRNET and SIPRNET circuits produced statistically lower queuing delays on the DBA-1 system for all but the Voice Overload workload. Queuing delay was also 11 ms higher than the static system on the SIPRNET circuit under the System Underload condition (Figure 4.14), with a 50.0 second monitoring period and 8192 bps allocation granularity. The data circuits performed well on three of the four loading levels because the bandwidth manager was able to effectively optimize bandwidth while keeping queuing delays low because of the low loading on the video circuit. As shown in Figures 4.11 and 4.15, however, queuing delays were higher than the static system in the Voice Overload condition. This is because the voice circuit was more heavily loaded. This means lower queuing delays based on higher

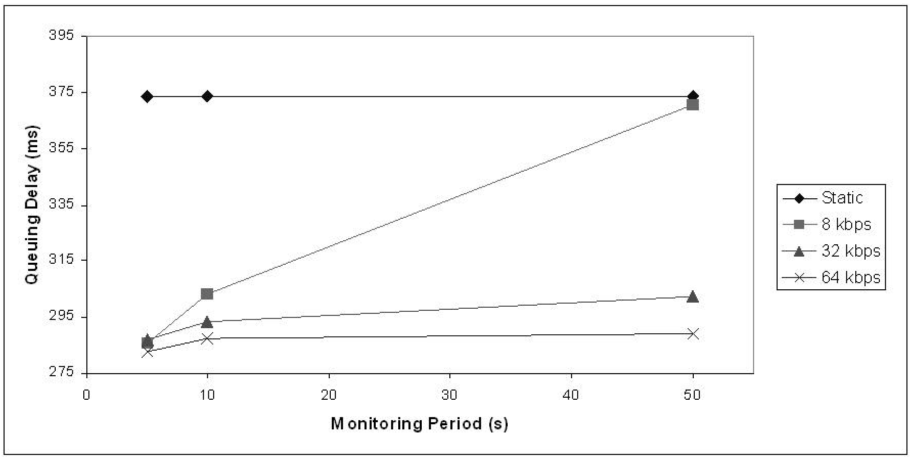

Figure 4.10. NIPRNET Circuit Queuing Delay — System Underload

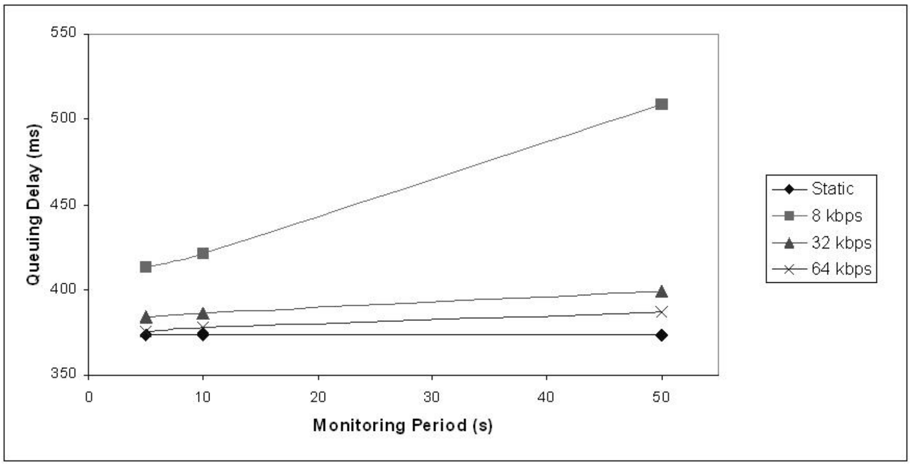

Figure 4.11. NIPRNET Circuit Queuing Delay — Voice Overload

average bandwidths for the voice circuit at the expense of queuing delays for other circuits.

Queuing delay tended to increase as monitoring period increased. This was true on all but the Voice and Data Overload workload. Queuing delay decreased on this loading level because the system was more stable with three of the four circuits heavily loaded. Furthermore, the heavy loading on the data circuits also contribute to greater stability for these circuits. Therefore, the bandwidth manager was able to optimize bandwidth and queuing delay much better as the system made fewer

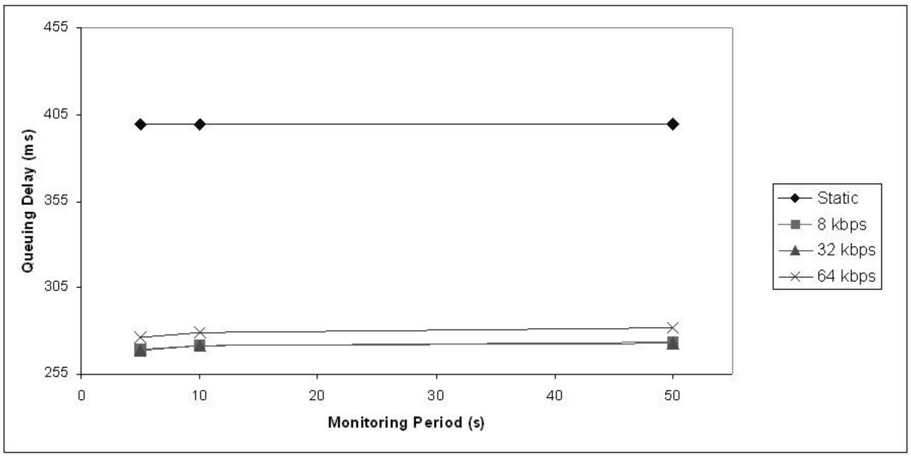

Figure 4.12. NIPRNET Circuit Queuing Delay — Data Overload

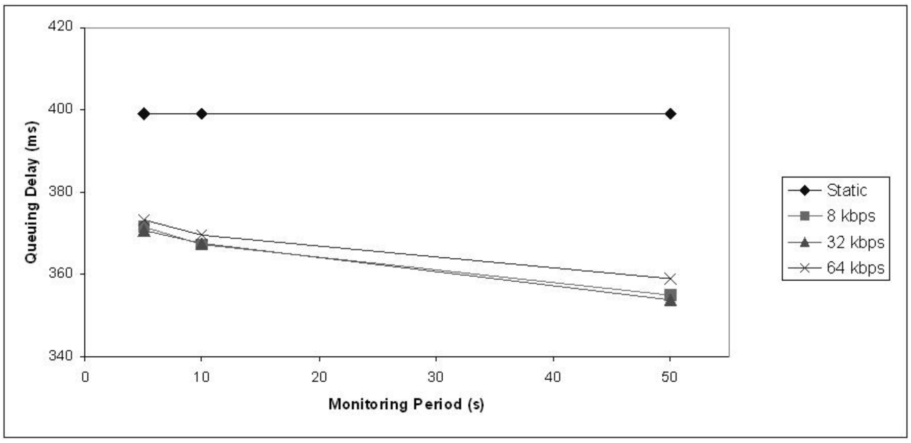

Figure 4.13. NIPRNET Circuit Queuing Delay — Voice and Data Overload

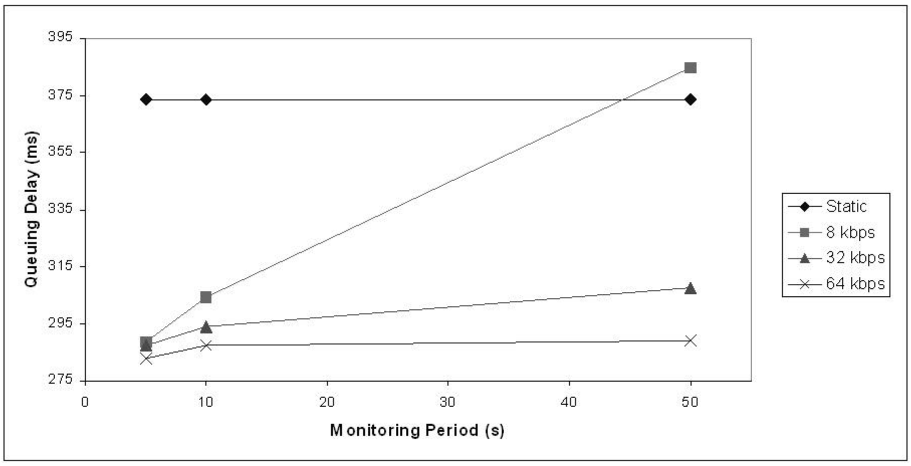

Figure 4.14. SIPRNET Circuit Queuing Delay — System Underload

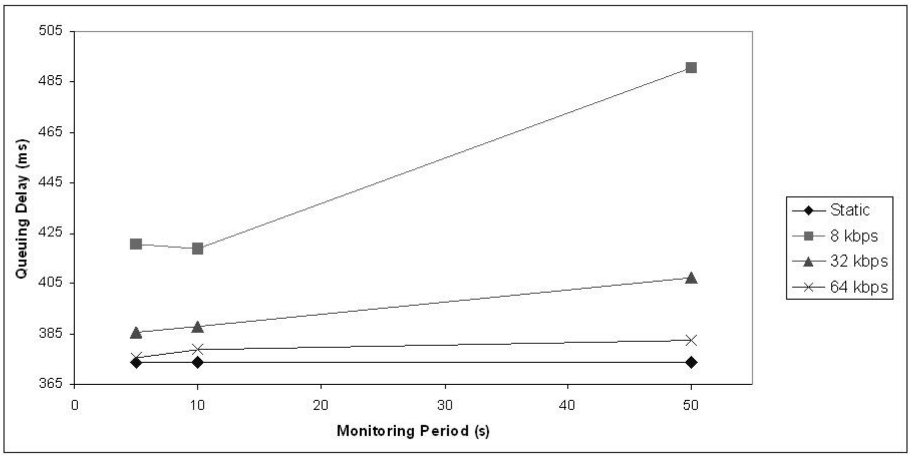

Figure 4.15. SIPRNET Circuit Queuing Delay — Voice Overload

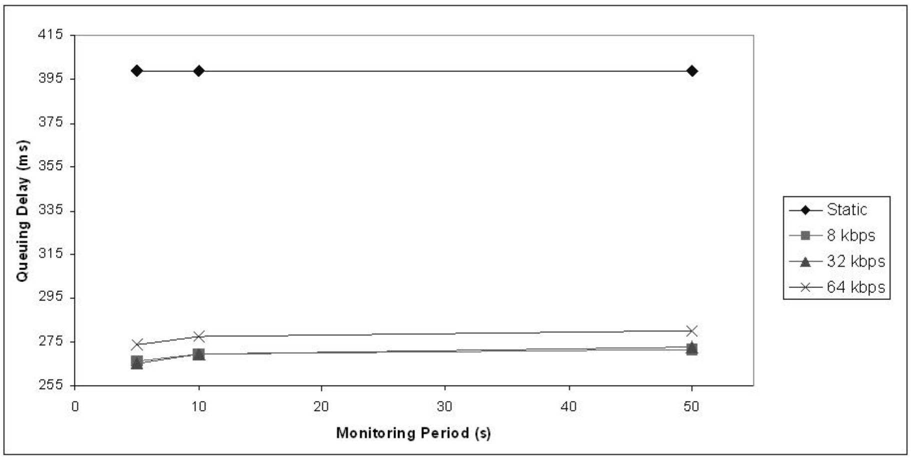

Figure 4.16. SIPRNET Circuit Queuing Delay — Data Overload

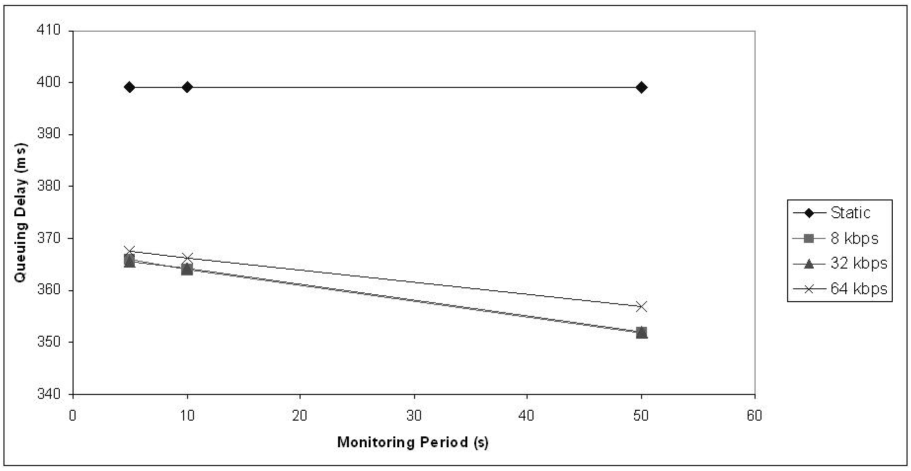

Figure 4.17. SIPRNET Circuit Queuing Delay — Voice and Data Overload

reallocations. Queuing delay increased dramatically with monitoring period when using an 8192 bps allocation granularity. The reason for this increase is unknown. However, because of excessive video circuit queuing delays (see Section 4.4.2.3), a change to the DBA-1 algorithm is required in any case. This queuing delay increase was not observed in subsequent versions of the algorithm.

The best overall data circuit queuing delays were observed using a 65536 bps allocation granularity and 5.0 sec monitoring period. In this configuration, the NIPRNET circuit produced average queuing delays up to 122.8 ms lower than the static system. Similarly, the SIPRNET circuit produced average queuing delays up to 125.7 ms lower than the static system. The highest queuing delays observed in this configuration were on the Voice Overload workload. However, average queuing delays observed at this loading level were only 2.3 ms higher than the static system on the NIPRNET circuit and 2.0 ms higher on the SIPRNET circuit. Clearly, in this configuration, the DBA-1 system produces lower queuing delays on average than the static system. The reasons for the lower queuing delays observed on this configuration are discussed in Section 4.4.2.5.

4.4.2.2 Voice Circuit. As Figure 4.19 shows, queuing delays were consistently statistically lower than the static system with the Voice Overload workload. Only one configuration under this loading condition produced an average queuing delay above the 309.1 ms average queuing delay of the static system. This configuration used a 65536 bps allocation granularity and 50.0 sec monitoring period and was an average of 18.9 ms greater than the static system. The lowest average queuing delay observed with this loading level was 222.7 ms using an 8192 bps allocation granularity and a 5.0 second monitoring period. Figure 4.18 shows that the two higher allocation granularities, combined with the two lower monitoring periods, produced average queuing delays slightly lower than the static system's 260.3 ms average with the System Underload workload. The best average queuing delay observed in this loading level was 253.1 ms, using a 65536 bps allocation granular-

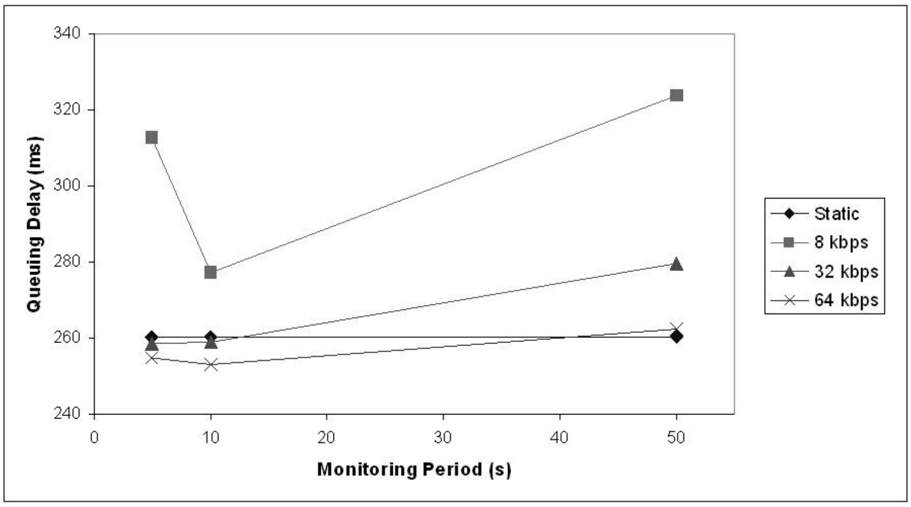

Figure 4.18. Voice Circuit Queuing Delay — System Underload

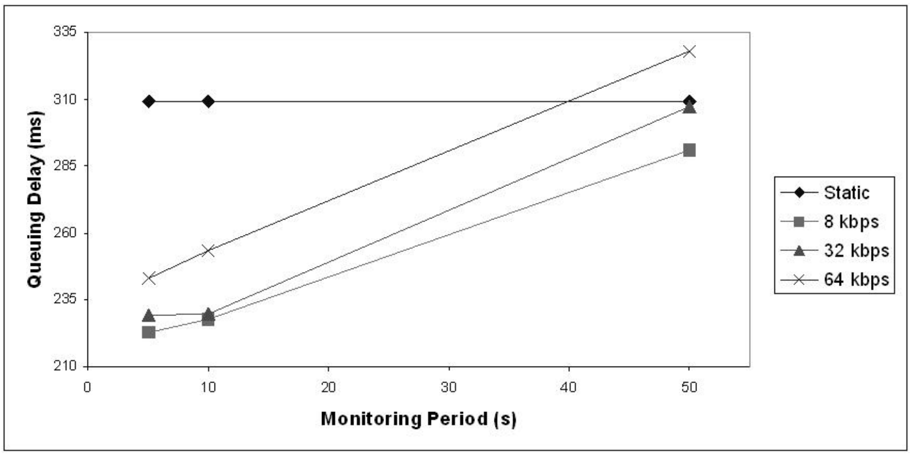

Figure 4.19. Voice Circuit Queuing Delay — Voice Overload

ity and a 10.0 second monitoring period. The other two loading levels shown in Figures 4.20 and 4.21 resulted in average queuing delays exclusively higher than the static system, regardless of configuration.

Queuing delay generally increased as the monitoring period increased. This result was expected, however, since longer monitoring periods imply a slower response to workload dynamics. Conversely, queuing delay generally decreased as allocation granularity increased. This was also expected since fewer reallocations would contribute to a more stable system and, thus, lower queuing delays. The exception

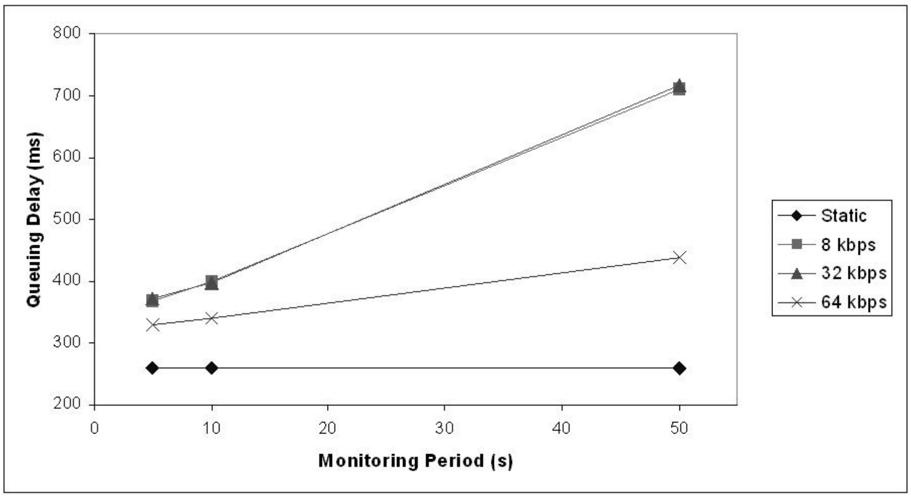

Figure 4.20. Voice Circuit Queuing Delay — Data Overload

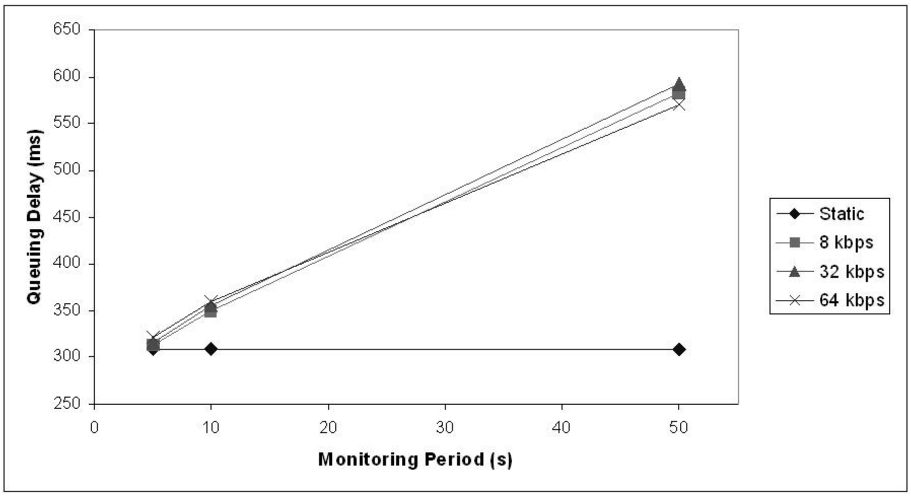

Figure 4.21. Voice Circuit Queuing Delay — Voice and Data Overload

to this was with the Voice Overload workload. In this case, the voice circuit was the only heavily loaded circuit. Therefore, the bandwidth manager could keep voice circuit queuing delay down by quickly responding to voice circuit demands.

The best overall voice circuit queuing delays were observed with a 65536 bps allocation granularity and a 5.0 second monitoring period. In this configuration, the voice circuit produced average queuing delays as much as 65.9 ms lower than the static system. The highest queuing delays observed in this configuration were with the Data Overload workload. Average queuing delays at this level, however, were significantly higher than the static system — an average of 69.8 ms higher. Although voice circuit queuing delays were generally close to those of the static system, delays this high could be considered excessive for real-time traffic. This issue is addressed in greater detail in Section 4.6.

4.4.2.3 Video Circuit. The video circuit produced average queuing delays statistically equivalent to the static system in only 5 of 36 configurations. Three of the five configurations were using the System Underload workload (Figure 4.22). Four of the five configurations used a 5.0 second monitoring period. As Figure 4.24 shows, with a 5.0 second monitoring period in the Data Overload, the 8192 bps allocation granularity produced an average queuing delay 9.0 ms higher than the static system; with the 32768 bps allocation granularity, queuing delays were an average of 14.8 ms higher than the static system. All other video circuit queuing delays were quite high. Even with a 5.0 second monitoring period, the best video circuit queuing delay observed with the Voice Overload workload was 679.9 ms as shown in Figure 4.23. Queuing delays were even higher with the Voice and Data Overload workload (Figure 4.25). The lowest queuing delay observed at this loading level was 864.4 ms. Average queuing delays for configurations with a 50.0 second monitoring period were no less than 833.8 ms and were as high as 5.482 sec. The effects of long monitoring periods were clearly seen on the video circuit. Because the video circuit was very lightly loaded but required a very high bandwidth, the

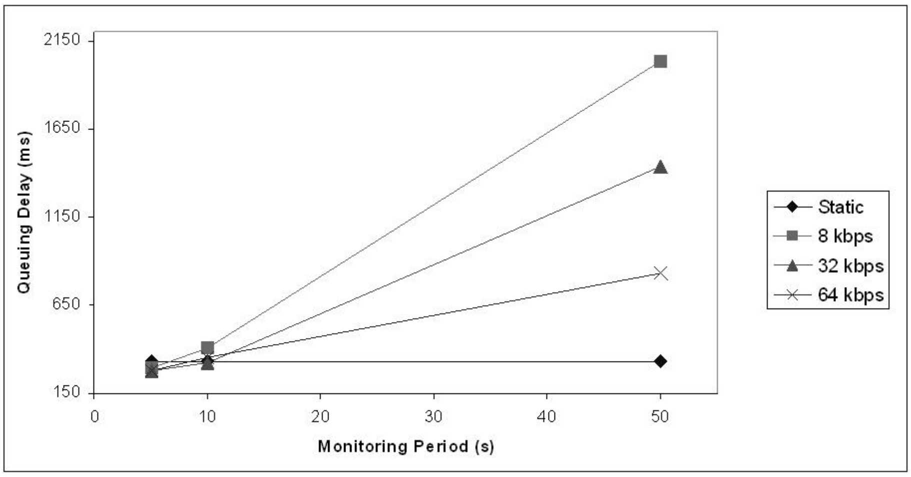

Figure 4.22. Video Circuit Queuing Delay — System Underload

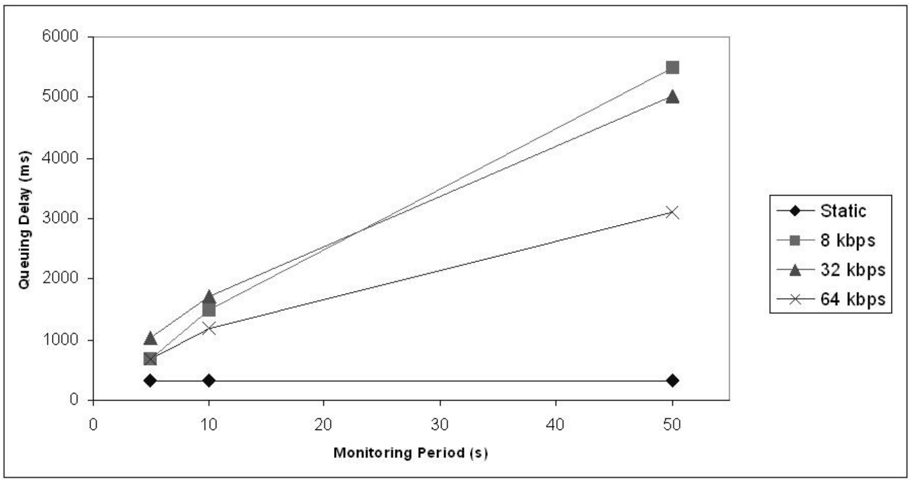

Figure 4.23. Video Circuit Queuing Delay — Voice Overload

dynamic system generally had trouble adjusting quickly enough to keep queuing delays down. Therefore, as with the voice circuit, video circuit queuing delays were generally unacceptable for real-time traffic.

4.4.2.4 Allocation of Variation. Tables 4.2 through 4.5 show the allocation of variation for each of the four circuits. Workload was a large contributor to the observed variation for all circuits. It accounted for 81.44% and 81.28% of the variation in the two respective data circuits, 43.68% in the voice circuit and

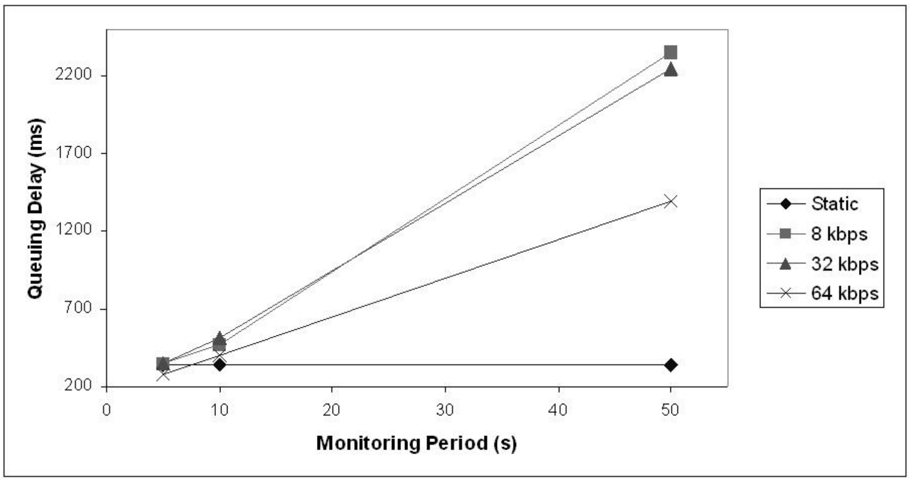

Figure 4.24. Video Circuit Queuing Delay — Data Overload

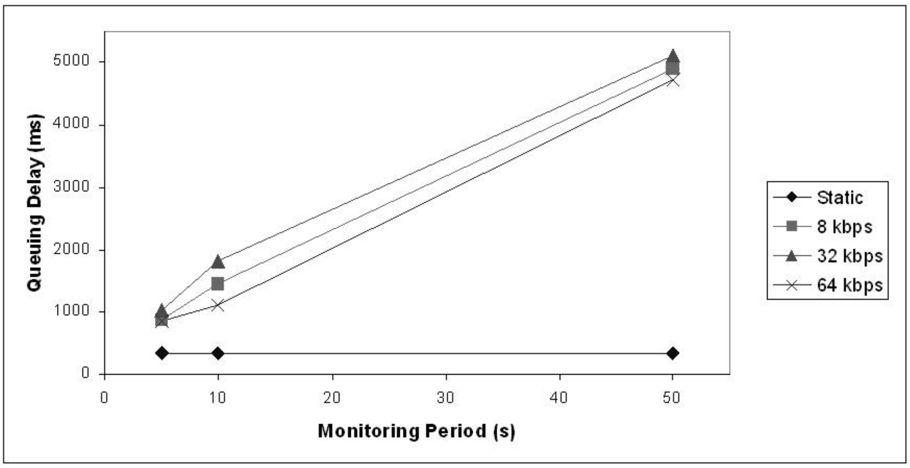

Figure 4.25. Video Circuit Queuing Delay — Voice and Data Overload

23.68% in the video circuit. Clearly how heavily each circuit is loaded will affect the circuits' queuing delays. If one circuit is more heavily loaded than the others, then the bandwidth manager is generally able to reallocate more bandwidth to it, keeping queuing delays down. Thus, queuing delays tend to be lower for that circuit when it is the sole heavily loaded circuit. Queuing delay tended to be higher than the static system on the Voice and Data Overload workload because the bandwidth manager was continuously reallocating between the three heavily loaded circuits. This could result in excessive jitter on voice and video circuits and should be examined more closely in future research.

Table 4.2. Voice Circuit Allocation of Variation using the DBA-1 Algorithm

Var Due to Workload	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to All Factors	Var Due to Error
43.68%	29.75%	4.61%	14.70%	2.68%	1.88%

Table 4.3. Video Circuit Allocation of Variation using the DBA-1 Algorithm

Var Due to Workload	Var Due to Monitoring Period	Var Due to Workload & Monitoring Period	Var Due to Error
23.68%	53.49%	11.40%	5.96%

Monitoring Period accounted for 29.75% of the variation in the voice circuit and 53.49% of the variation on the video circuit. This factor had little effect on the data circuits because the data traffic had similar characteristics regardless of the length of the period of observation (i.e., monitoring period). The reason the video circuit was affected much more is that its mean off period was long compared to

Table 4.4. NIPRNET Circuit Allocation of Variation using the DBA-1 Algorithm

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
81.44%	3.19%	5.06%	3.06%	1.99%	2.13%	1.65%

Table 4.5. SIPRNET Circuit Allocation of Variation using the DBA-1 Algorithm

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Error
81.28%	3.19%	4.86%	2.77%	2.60%

the data circuits. Therefore, the video circuit's bandwidth was reduced considerably while inactive. When it became active, however, its input buffer size would grow until the monitoring period expired prior to reallocation. The result of such little activity on the video circuit was an implicit prioritization of other circuits above the video circuit. This is because the video circuit required such a large number of time slots to operate with minimal delay. However, these time slots were rarely available because they were allocated to other circuits with a higher demand. This problem is addressed again in Section 4.5. The voice circuit was affected by the monitoring period because its utilization never got above 43% (i.e., 1 sec on out of every 2.35 sec). Therefore the bandwidth manager reduced the voice circuit's service rate to match its measured utilization. The arrival rate never decreased, however, causing the input buffer size to grow during on periods. This resulted in the appearance of a higher utilization, which caused an oscillation back to a higher service rate. When the monitoring period was higher, the voice circuit had to wait longer for the adjustment to take place, resulting in higher average queuing delays.

4.4.2.5 Best Configuration. The 65536 bps allocation granularity and 5.0 sec monitoring period resulted in the best overall configuration for queuing delay. The 65536 bps granularity performed better because reallocations were not made as often. This resulted in larger granularities needed for a reallocation. This in turn meant the system did not have to adjust as often which resulted in fewer times that the input buffers filled up due to a reallocation.

The 5.0 second monitoring period gave the best performance because the system could react quickly to a circuit needing more bandwidth. The 10.0 and 50.0

second monitoring periods caused input buffer sizes to increase considerably while the system waited to determine which circuits to allocate bandwidth between.

4.4.3 Choice of Distribution for Data Circuits. Classical modeling of network traffic has used the exponential distribution to model inter-arrival times [Jai91, SAH94]. Recent research has shown, however, that data traffic does not fit this model well because it is more bursty by nature [LTW94, PaF95, CrB97]. A traffic model based on the Pareto distribution seems to model data traffic more closely. Therefore, some simulations were done using the Pareto distribution with a shape parameter of $a = 1.6$ in place of the exponential distribution. Simulation results indicate that for the configuration with an 8192 bps allocation granularity and 5.0 second monitoring period, the queuing delay difference between the two distributions is less than 6.5 ms at 90% confidence (see Figure 4.26). This difference is negligible, however, since average queuing delays were in excess of 370 ms. Utilizations were also very close. For example, the model using the exponential distribution had an average utilization of 47.57% with the above configuration on the heaviest loading level, compared to 49.30% from the model using the Pareto distribution. Therefore, since the aggregate utilization and data circuit queuing delays match very closely, it was concluded that the exponential distribution produces similar results to that of the Pareto distribution for the metrics collected in this study.

4.4.4 Overall Assessment of the DBA-1 Algorithm. Clearly the DBA-1 algorithm provided higher utilizations than the static allocation method under all loading conditions. Unfortunately, these gains came at the expense of queuing delay. Queuing delays reached up to 864 ms on the video circuit using the best configuration, indicating that this solution is unacceptable for real-time traffic.

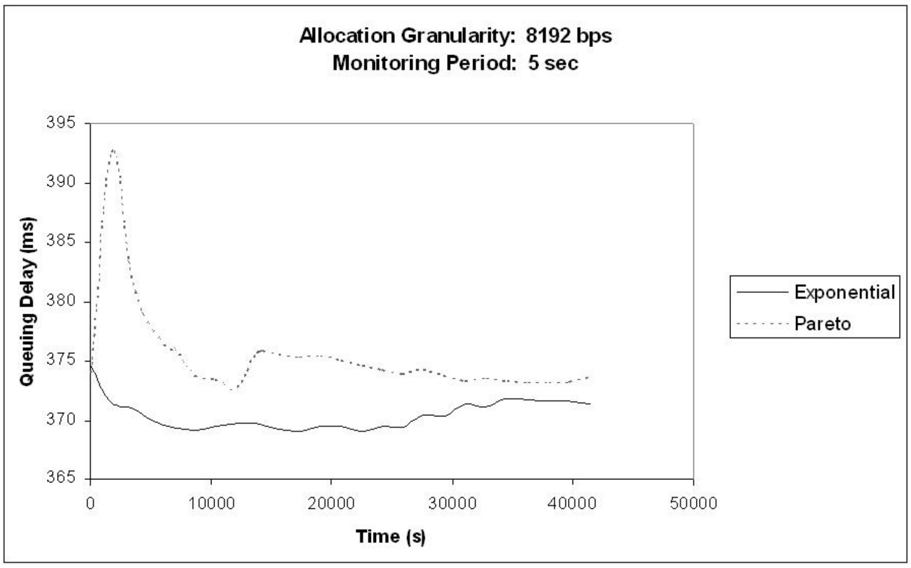

Figure 4.26. Data Circuit Queuing Delays: Exponential vs. Pareto Distribution

4.5 DBA with CBR Circuit Priority — Second Iteration

Because the pure DBA-1 algorithm failed to produce acceptable queuing delay results, especially for the video circuit, the algorithm was modified to give priority to the video circuit (referred to as DBA-2). Figure 4.27 shows the state transition diagram for the modified algorithm. This model is the same as that shown in Figure 4.1 with the following additions. In the *arrival* state, every arriving frame is examined to determine which circuit it arrived from. Once an arriving video frame was detected, the system checked to ensure the video circuit was assigned enough time slots to correspond to its peak rate. If the video circuit needed an additional allocation of time slots, an interrupt was generated. This interrupt sent the system to the *reset_priority* state, which systematically removed unused time slots from each circuit based on current measured utilization levels. If enough time slots could not be found to reallocate to the video circuit, the system entered the *reset_full* state, which set each circuit's time slot allocations back to the originally-assigned levels.

4.5.1 Queuing Delay. Simulations were run for the configuration using a 65536 bps allocation granularity and 5.0 second monitoring period since this was the

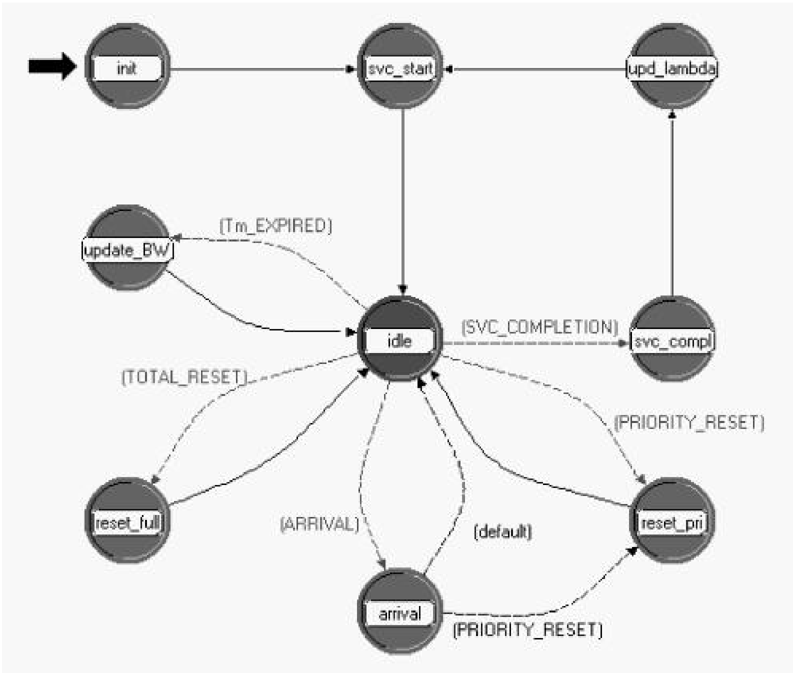

Figure 4.27. DBA with CBR Priority State Transition Diagram

best overall configuration observed with the DBA-1 algorithm. The dynamic system performed much better with the CBR priority feature added. The voice and data circuits even had slightly lower average queuing delays, but overall this difference was negligible. The video circuit, however, had much lower queuing delays — in some cases, less than half of that observed using the DBA-1 algorithm. Figure 4.28 compares the average video circuit queuing delays of the two DBA versions and the static allocation method for each loading level in the above configuration. The CBR priority feature decreases the queuing delay difference considerably for all workloads. In this configuration, the maximum mean difference observed between the DBA-2 algorithm and the static algorithm was 137 ms, a 74.08% decrease from the DBA-1 algorithm. Every circuit was able to experience a queuing delay decrease due to the bandwidth manager's increased capability to manage the time slots available to each circuit. Giving priority to the CBR circuit ensures that the necessary time slots are available as soon as possible. In addition, the bandwidth manager can also continue

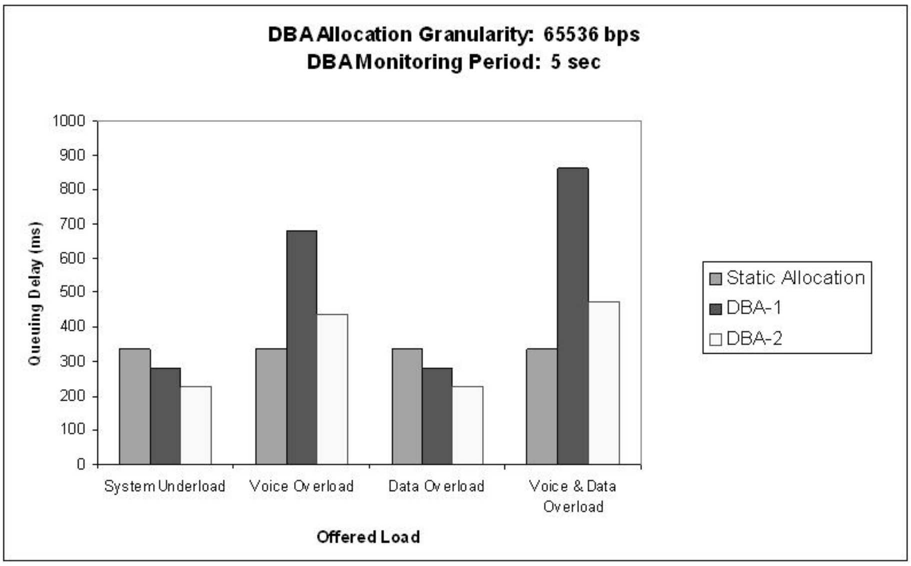

Figure 4.28. Comparison of Previous Video Circuit Queuing Delays and DBA-2 Queuing Delays

to provide more time slots to the other circuits while the video circuit is inactive, thus reducing overall queuing delays.

4.5.2 Utilization. Aggregate utilization was only negligibly lower using the CBR priority addition. Figure 4.29 shows the utilizations for each of the algorithms. The largest observed difference in mean utilization between the DBA-1 algorithm and the DBA-2 algorithm was 0.55%. Therefore, this addition improved queuing delay without adversely affecting the utilization gains of the algorithm or their statistical significance. This was not unexpected, however. Since the offered load was the same for both with and without the CBR priority feature, it is expected that the aggregate utilization would be about the same. Refer to Appendix B for Utilization Confidence Intervals.

4.5.3 Overall Assessment of the DBA-2 Algorithm. The improved algorithm retained the utilization gains achieved under the DBA-1 algorithm. Furthermore, queuing delays decreased across the board — in some cases up to 74% — and the voice and data circuits produced queuing delays at or below that of the static

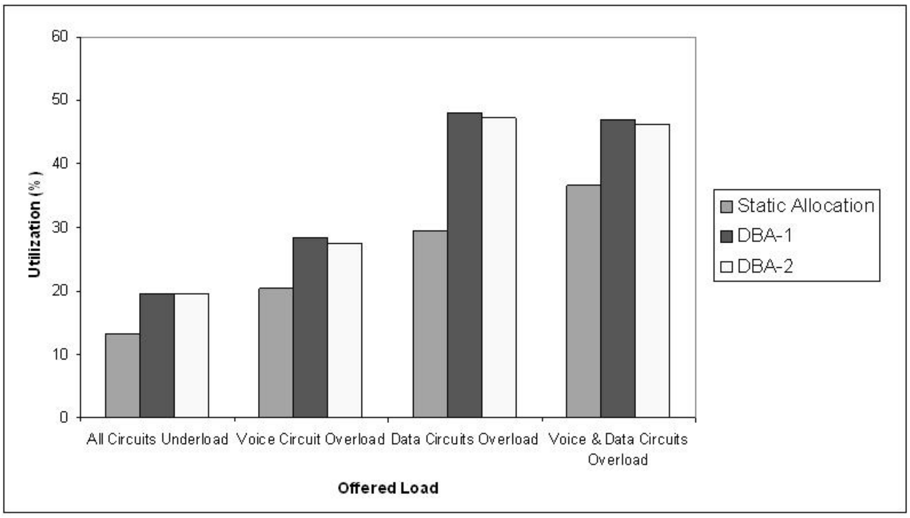

Figure 4.29. Comparison of Previous Utilizations and DBA-2 Utilization

model for the best configuration. However, video circuit queuing delays were still 139 ms greater under the best DBA factor combination than the static model — a 41% difference. Consequently, queuing delays are still unacceptable despite the utilization gains achieved with the DBA-2 algorithm.

4.6 Static and Dynamic Allocation with Work Conservation

Up to this point, the DBA algorithm's performance has been compared to that of the static model, which represents static assignment TDM. Static assignment TDM, though, does not lend itself well to supporting real-time traffic. For example, video circuit queuing delays observed using the static model average 1/3 of a second. This is because the best case occurs when frames arrive at the beginning of a circuit's allocation (resulting in a zero waiting time) and the worst case occurs when frames arrive immediately following a circuit's allocation (resulting in a 2/3 second waiting time). Furthermore, if a particular circuit has no frames to transmit during its allocation, then those slots go unused.

The ITU's 1996 Recommendation, G.114, states that most users can tolerate a total end-to-end delay for two-way voice traffic between 300 and 800 ms [ITU96].

We will assume the same standard for 2-way video traffic as well. While some users may find an 800 ms delay acceptable, the ITU's recommendation states that an 800 ms delay could result in noticeable delay for some users. Noticeable delays such as this are common for tactical military networks, however. The 300-800 ms delay figure includes not only the initial queuing delay, but also queuing delays at each hop along the way to the destination and transmission delays. Consider also that tactical military communications networks often tie into the global communications network through a satellite connection, which adds an additional 250 ms to the transmission time. It is clear that a large queuing delay such as the average 1/3 of a second seen under the static model could easily result in end-to-end delays nearing or exceeding 800 ms.

4.6.1 Static Allocation with Work Conservation. Work conservation ensures that every available time slot is filled as long as at least one circuit has a frame waiting. This concept was incorporated into the static allocation algorithm in order to reduce the queuing delays experienced by the strict static allocation method. The new algorithm worked in the same manner as the original method with one exception: if a circuit's input buffer becomes empty during its time slot allocation, the other circuits' input buffers are polled, in turn. The first input buffer found with a waiting frame is inserted into the time slot. The only way that a time slot would go empty then, is if all input buffers are empty. For example, if Circuit 1 is inactive during its time slot allocation, then Circuit 2's input buffer will be examined for a waiting frame. If one exists, it is inserted into the time slot; if not, Circuit 3's input buffer is examined, and so on.

4.6.1.1 Utilization. Utilization was unchanged from that of the strict static model. This was expected since the offered loads were the same between the two systems. The same number of frames were being submitted for a particular offered load. The only difference is that they were serviced in a more efficient manner,

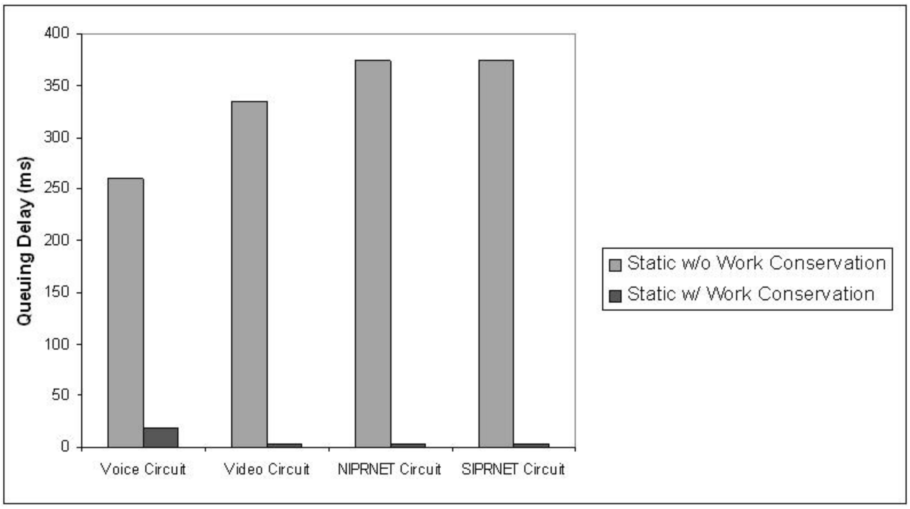

Figure 4.30. Comparison of Static Allocation Method Queuing Delays — System Underload

thus reducing queuing delay. The number of empty time slots per cycle, however, remained the same.

4.6.1.2 Queuing Delay. Queuing delay was reduced by as much as two orders of magnitude with the implementation of the work conservation feature. Figures 4.30 through 4.33 show the difference under each of the loading levels. The video circuit experienced the lowest queuing delays. The highest average video circuit queuing delay observed was 5.8 ms, down from 335.7 ms. The voice circuit experienced the highest average queuing delays, ranging from 19.3 ms on the System Underload (Figure 4.30) to 23.9 ms on the Voice and Data Overload (Figure 4.33).

The reason for the higher queuing delay observed on the voice circuit is due to the work conservation algorithm's implementation. The algorithm looks to the next circuit in sequence to fill a potentially-unused time slot. Therefore, the NIPRNET circuit had "first priority" on all unused time slots of the rarely-active video circuit. Because the voice circuit fell immediately before the video circuit, sequentially, it had "last priority." Of course, the voice circuit had first priority on the SIPRNET circuit but the amount of unused time slots were much less than from the video

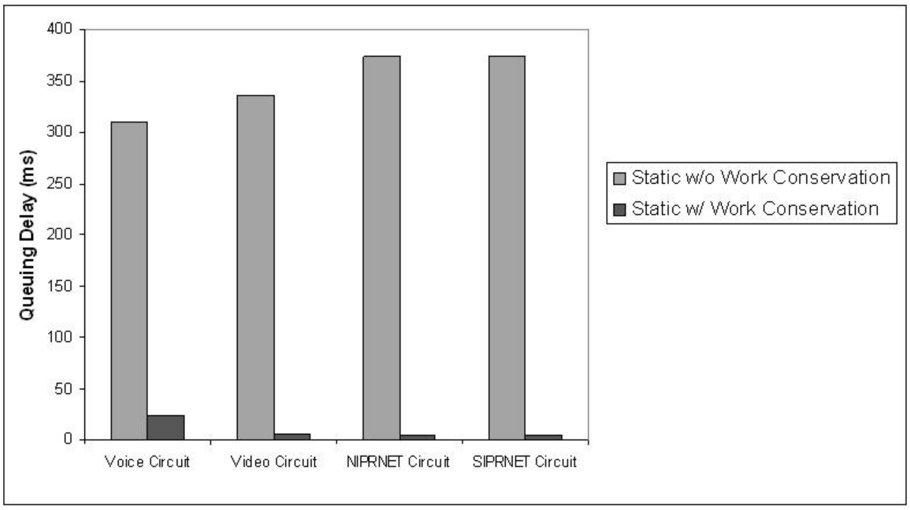

Figure 4.31. Comparison of Static Allocation Method Queuing Delays — Voice Overload

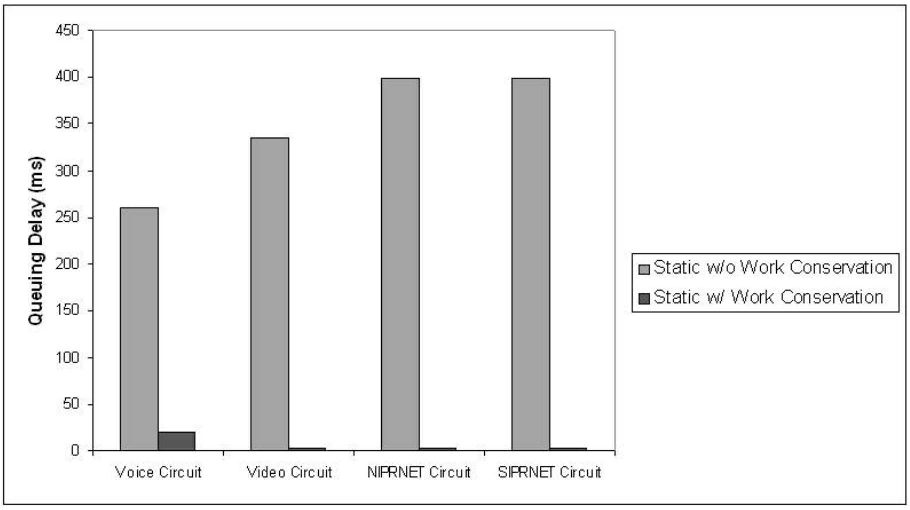

Figure 4.32. Comparison of Static Allocation Method Queuing Delays — Data Overload

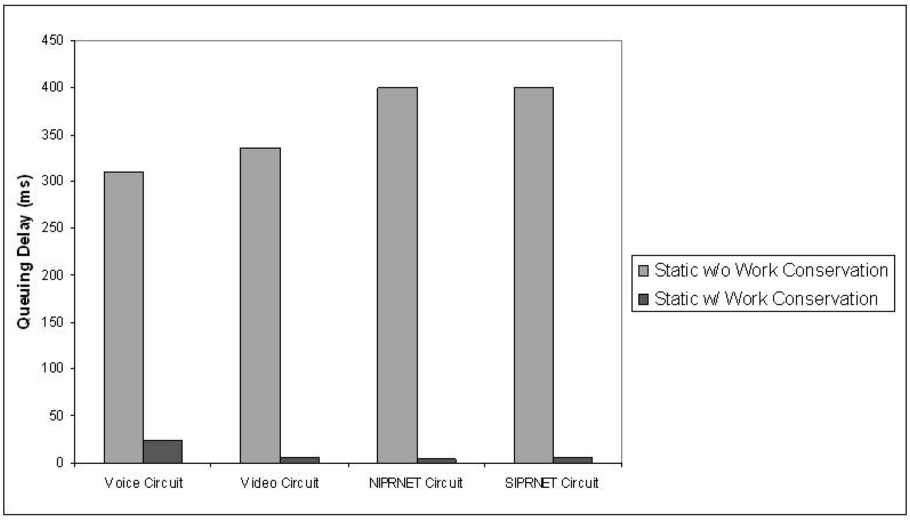

Figure 4.33. Comparison of Static Allocation Method Queuing Delays — Voice and Data Overload

circuit. There are two alternatives to eliminating this problem. The first is to ensure that all circuits are prioritized based on bandwidth and delay requirements. For example, if the video circuit has the highest priority and the voice circuit has the second highest priority, then the voice circuit should be given priority on any of the video circuit's unused time slots. The second alternative is to randomly select which circuit will have "first priority" upon encountering a potentially-unused time slot. Whether this issue is mitigated or not, however, the algorithm's ability to fill potentially-unused time slots clearly has a tremendous impact on the queuing delay experienced by arriving frames.

4.6.2 Dynamic Allocation with Work Conservation — Third Iteration. The work conservation feature was also incorporated into the DBA-2 algorithm (referred to as DBA-3) and compared against the new static system as a baseline. Simulations were then run to determine if the effects on queuing delay were as dramatic for the DBA system as the static system.

4.6.2.1 Utilization. Utilization was very close to that observed using the DBA-1 algorithm. The largest mean difference observed was 0.55%, which is only a 1.8% change from the original value. Therefore, the statistically significant utilization gains achieved with the DBA-1 algorithm were not affected by the addition of the work conservation feature. The highest average utilization gains over the static system were again using the 32768 bps granularity and 5.0 sec monitoring period configuration — the same as with the DBA-1 algorithm. The configuration resulting in the lowest utilization gains also matched that observed using the DBA-1 algorithm. These results further indicate that the introduction of the work conservation feature had no effect on aggregate utilization.

The allocation of variation nearly matched that seen with the DBA-1 algorithm. Workload accounted for 99.3% of the variation observed in the data, while monitoring period and allocation granularity had a negligible effect. The unexplained variation accounted for 0.30%. This result indicates first that offered load is almost solely responsible for the utilization performance of the system. It also indicates, however, that, for a given workload, the DBA algorithm can increase utilization approximately the same irrespective of allocation granularity or monitoring period.

4.6.2.2 Queuing Delay. With the work conservation feature, the DBA-3 algorithm performed well across all configurations and offered loads. The following sections analyze the queuing delays observed for each of the circuit types, in turn. The DBA-3 results are then examined to determine which configuration performed the best.

4.6.2.2.1 Video Circuit. With the inclusion of both the CBR priority and work conservation features, the video circuit had outstanding queuing delay results compared to previous results. All configurations produced statistically equivalent or better queuing delays on the Data Overload as shown in Figure 4.36. Similarly, as shown in Figure 4.34, all but two configurations produced statistically equivalent or better queuing delays on the System Underload. The two that were statistically different employed 5.0 second monitoring periods and 32768 and 65536 bps allocation granularities and resulted in mean differences no greater than 0.56 and 0.70 ms, respectively, at 90% confidence. One reason for the good performance on these two workloads, however, deals with the sequencing of the circuits as explained in Section 4.6.1.2. The voice circuit is only lightly loaded in both of these configurations allowing the video circuit more opportunities to fill the voice circuit's unused time slots as necessary. Queuing delays were higher on the Voice Overload and Voice and Data Overload levels as shown in Figures 4.35 and 4.37, respectively. Average video circuit queuing delays on the static system were 5.03 ms and 5.77 ms on these two respective loading levels. The DBA system produced higher queuing delays but were much closer to the static system than the queuing delay differences observed without the inclusion of the work conservation feature. With the Voice Overload workload shown in Figure 4.35, the largest mean difference observed was 2.17 ms, using an 8192 bps allocation granularity and 5.0 second monitoring period. Queuing delay differences were slightly higher on the Voice and Data Overload level (Figure 4.37), but the largest mean difference observed was only 4.92 ms, again using an 8192 bps allocation granularity and 5.0 second monitoring period. Compared to the maximum delay for real-time traffic discussed in Section 4.6, several DBA-3 system configurations would perform acceptably despite the slight increases in queuing delays.

In general, configurations using a 10.0 second monitoring period had lower queuing delays. Because of the long inactive periods on the video circuit, longer monitoring periods did not allow the system to adjust to circuit activations as quickly as lower monitoring periods. Shorter monitoring periods resulted in a large number of reallocations likely causing excessive system jitter.

4.6.2.2.2 Data Circuits. The data circuits also performed well with the added features. However, all configurations and workload combinations

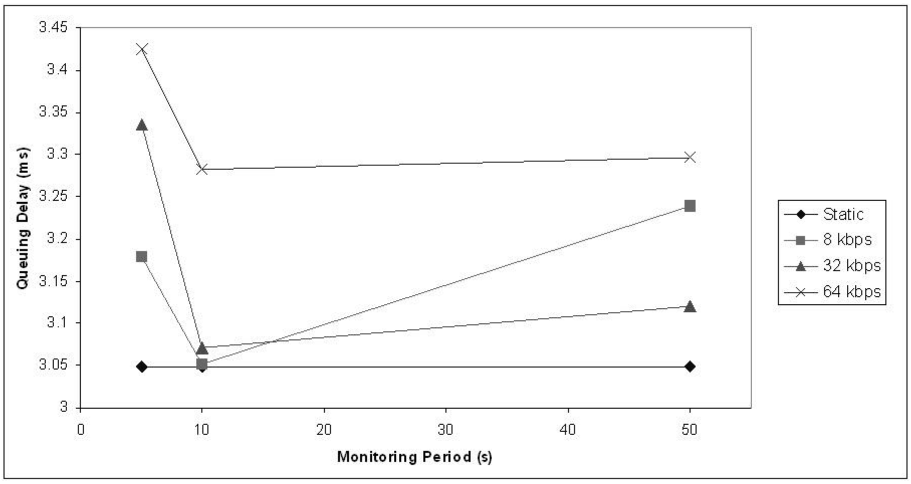

Figure 4.34. Video Circuit Queuing Delay Comparison — System Underload

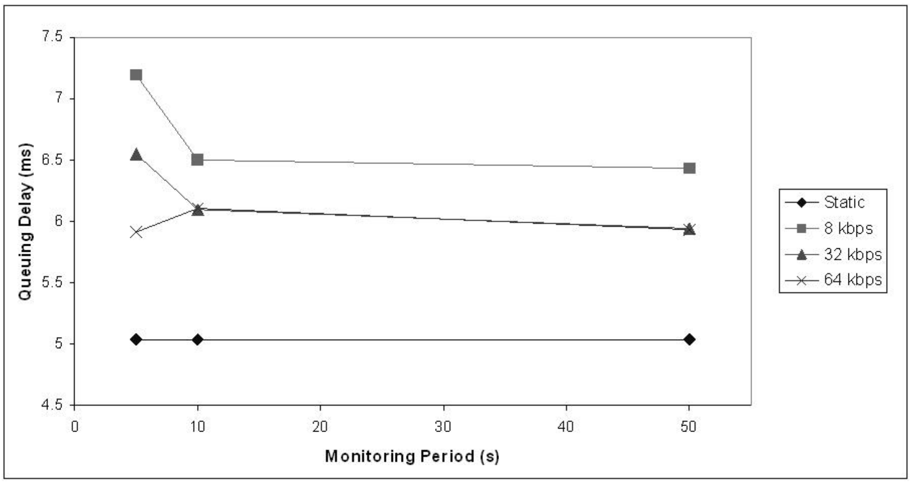

Figure 4.35. Video Circuit Queuing Delay Comparison — Voice Overload

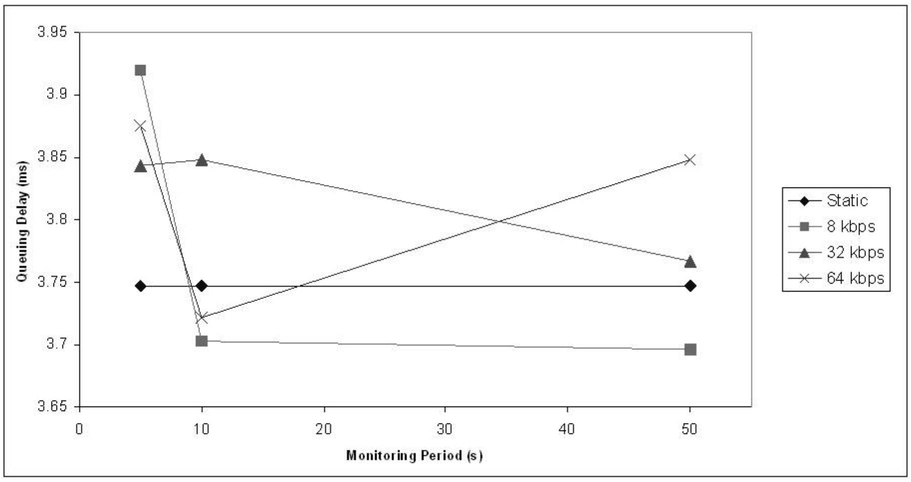

Figure 4.36. Video Circuit Queuing Delay Comparison — Data Overload

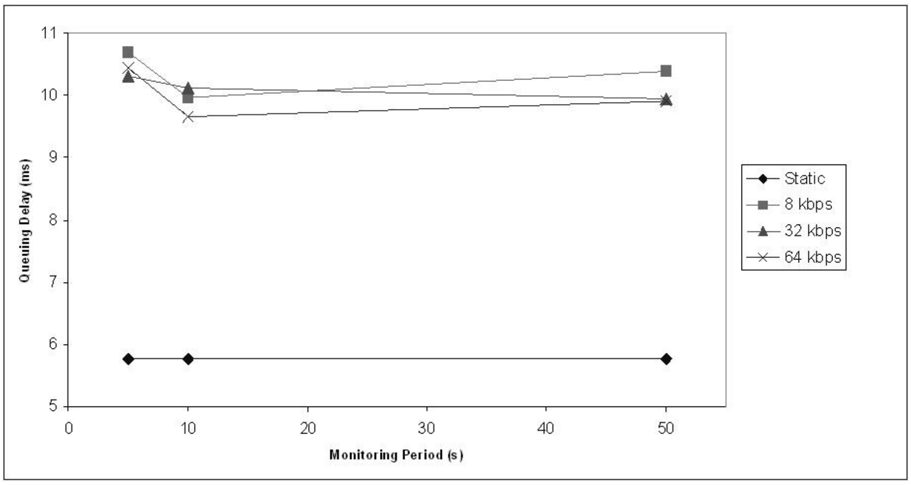

Figure 4.37. Video Circuit Queuing Delays Comparison — Voice and Data Overload

resulted in statistically higher queuing delays over the static system. Refer to Appendix B for 90% confidence intervals. Despite this short-coming, both data circuits performed acceptably under all configurations. Average queuing delays were only slightly higher than the static system with the System Underload workload. As shown in Figures 4.38 and 4.42, the highest average queuing delays observed in this loading level were 3.36 ms on the NIPRNET circuit and 3.51 ms on the SIPRNET circuit, respectively, using an 8192 bps allocation granularity and 5.0 second monitoring period. This compares with the static system's 3.01 and 3.15 ms averages. Average NIPRNET circuit queuing delays were still less than 5.0 ms in the Data Overload condition; as Figure 4.40 shows, the highest average queuing delay observed was 4.92 ms using an 8192 bps allocation granularity and 5.0 second monitoring period. Average queuing delays on the remaining loading levels were higher as shown in Figures 4.39, 4.41, and 4.43-4.45. Average NIPRNET circuit queuing delays were lower than SIPRNET delays. Configurations with a 65536 bps allocation granularity had average queuing delays less than 10.0 ms for all loading levels and monitoring periods. The largest average queuing delay observed on the NIPRNET circuit was 12.30 ms, shown in Figure 4.39, using an 8192 bps allocation granularity and 5.0 second monitoring period. Average SIPRNET circuit queuing delays were as high as 21.63 ms on the Voice and Data Overload (Figure 4.45), again using an 8192 bps allocation granularity and 5.0 second monitoring period. This compares to a 5.91 ms average queuing delay on the static system. Delays this high are still acceptable, however, since data traffic is not held to the same end-to-end delay standard as real-time traffic. Furthermore, the highest offered load on the SIPRNET circuit in the worst DBA-3 configuration still resulted in a 94.6% drop in queuing delay from the static assignment TDM model.

Data circuit queuing delays tended to decrease as monitoring period increased, but only slightly. Because the characteristics of the data traffic were the same over any period of observation, observed queuing delays were similar for a given allocation

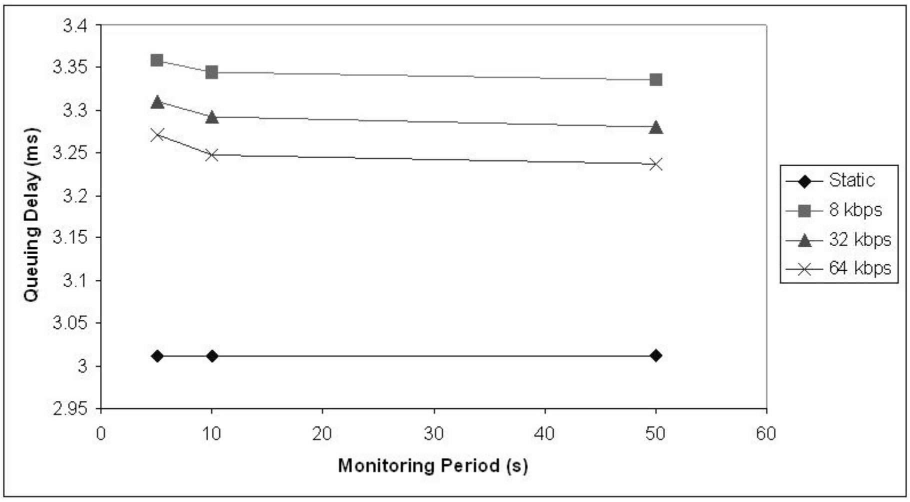

Figure 4.38. NIPRNET Circuit Queuing Delay Comparison — System Underload

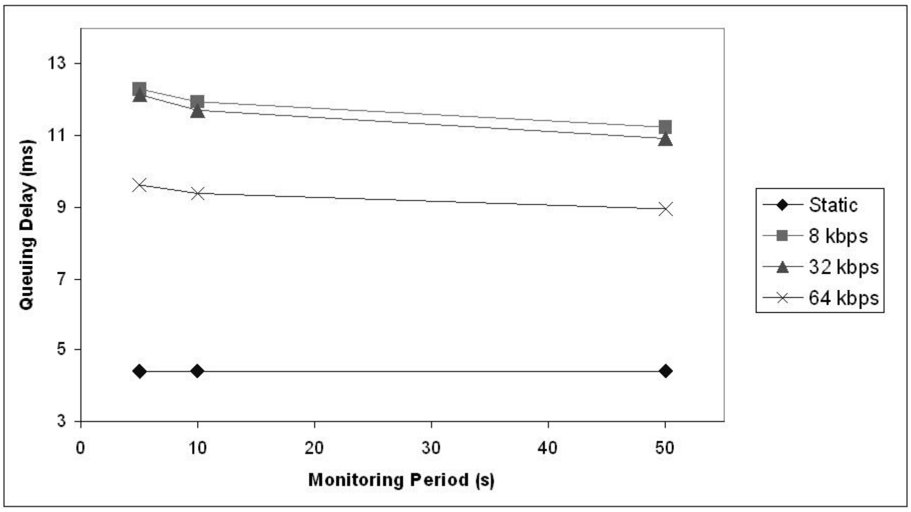

Figure 4.39. NIPRNET Circuit Queuing Delay Comparison — Voice Overload

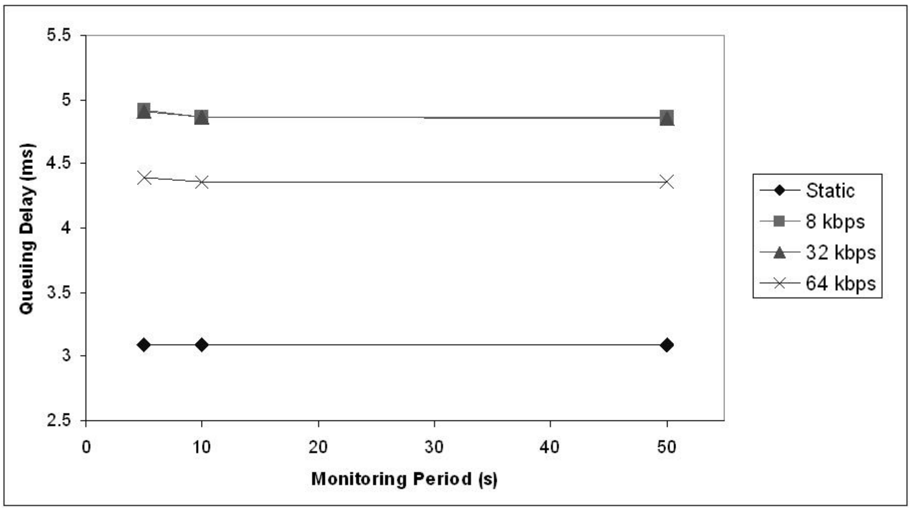

Figure 4.40. NIPRNET Circuit Queuing Delay Comparison — Data Overload

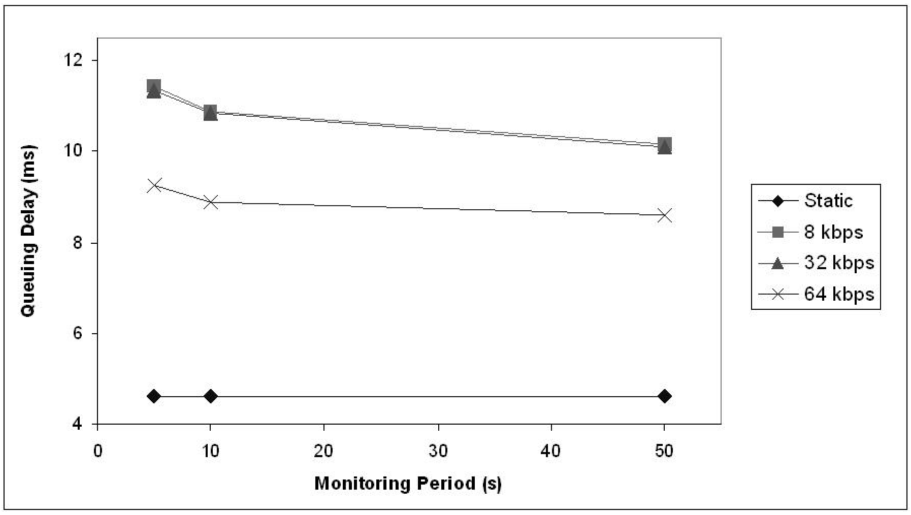

Figure 4.41. NIPRNET Circuit Queuing Delay Comparison — Voice and Data Overload

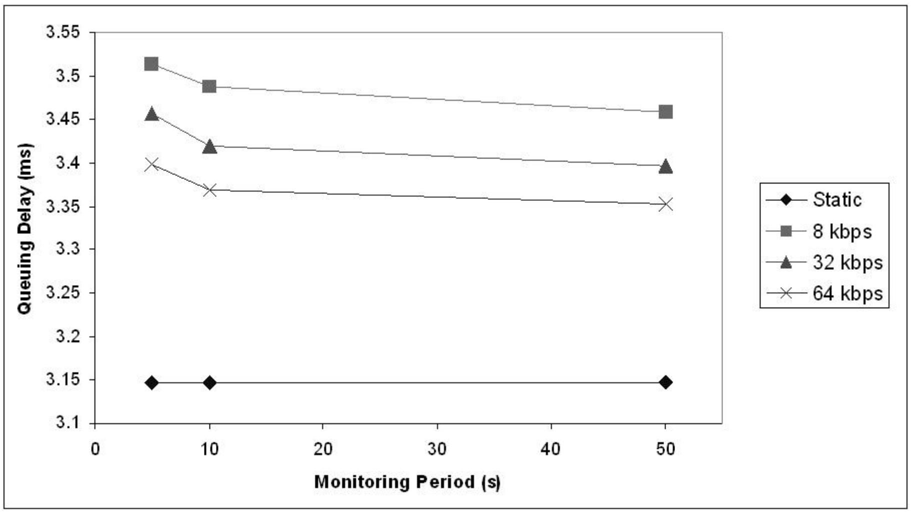

Figure 4.42. SIPRNET Circuit Queuing Delay Comparison — System Underload

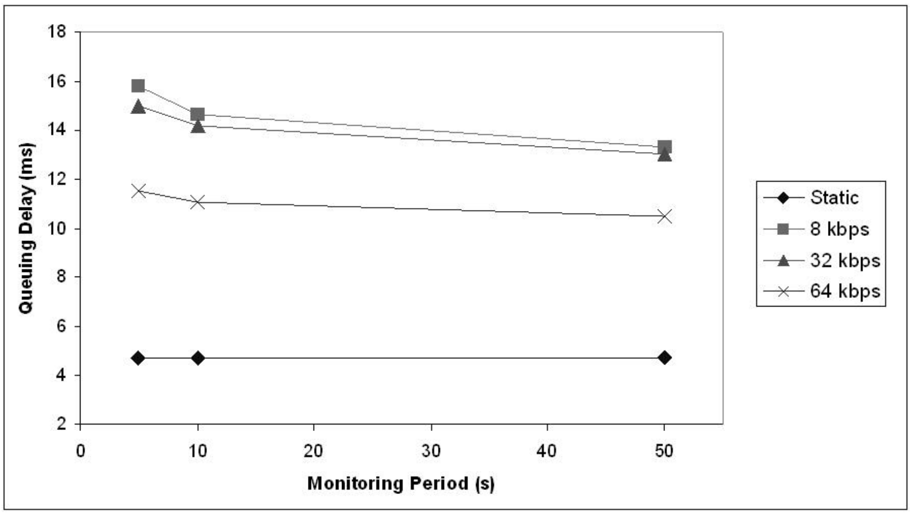

Figure 4.43. SIPRNET Circuit Queuing Delay Comparison — Voice Overload

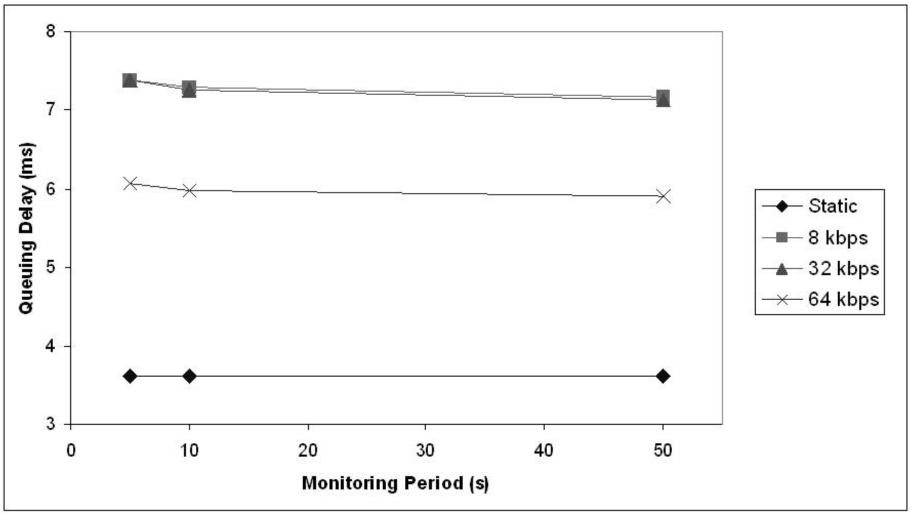

Figure 4.44. SIPRNET Circuit Queuing Delay Comparison — Data Overload

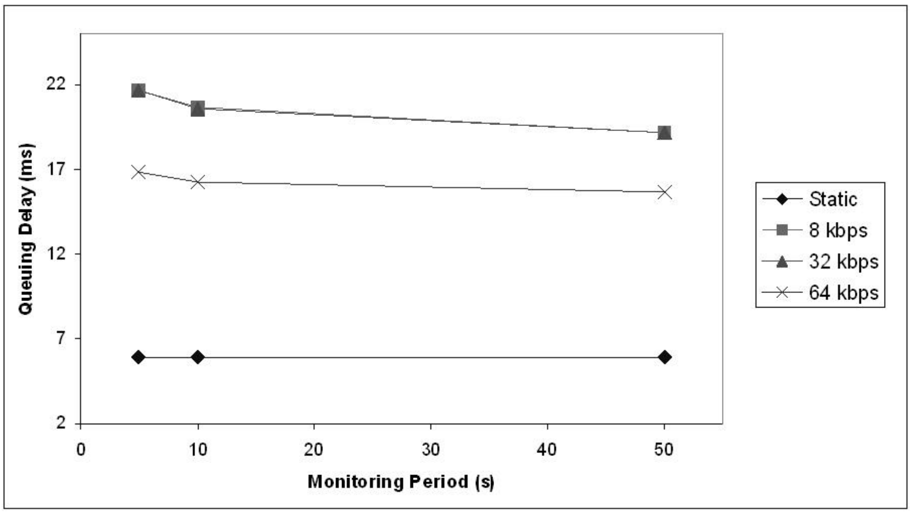

Figure 4.45. SIPRNET Circuit Queuing Delay Comparison — Voice and Data Overload

granularity irrespective of the length of the monitoring period. However, the longer monitoring period resulted in fewer reallocations. This contributed to a more stable system and, thus, lower queuing delays. Queuing delays were also lower when using the 65536 bps allocation granularity. This result is also due to the stability of the system created by the less frequent reallocations. The other two allocation granularities tended to produce nearly identical results. This is mainly due to the way allocations (and deallocations) were made to/from the voice circuit. A phone call was defined to require 32768 bps of bandwidth. Therefore, bandwidth had to be allocated to/from the voice circuit in granularities of this size regardless of the bandwidth manager's specified allocation granularity. This resulted in roughly the same number of reallocations with the 8192 bps granularity as with the 32768 bps granularity.

4.6.2.2.3 Voice Circuit. Queuing delays for the voice circuit were much improved over that of previous models but higher than those observed on the other circuits. As with the data circuits, though, all configuration and workload combinations resulted in statistically higher queuing delays. Refer to Appendix B for the 90% confidence intervals. Average DBA-3 queuing delays were lowest on the System Underload workload as expected. Figure 4.46 shows that average voice circuit queuing delays on the DBA-3 system at this loading level ranged from 23.10 ms with a 65536 bps allocation granularity and 50.0 second monitoring period to 33.32 ms with an 8192 bps allocation granularity and 5.0 second monitoring period. By comparison, average voice circuit queuing delays on the static system were 19.33 ms at this loading level. Average queuing delays were much higher on the Data Overload and Voice and Data Overload workloads as Figures 4.48 and 4.49 show. The lowest average queuing delay observed on these workloads was 37.43 ms, using a 65536 bps allocation granularity and 50.0 second monitoring period. The highest average queuing delay observed on these workloads was 61.60 ms using a 32768 bps allocation granularity and 50.0 second monitoring period. While these queuing delays appear

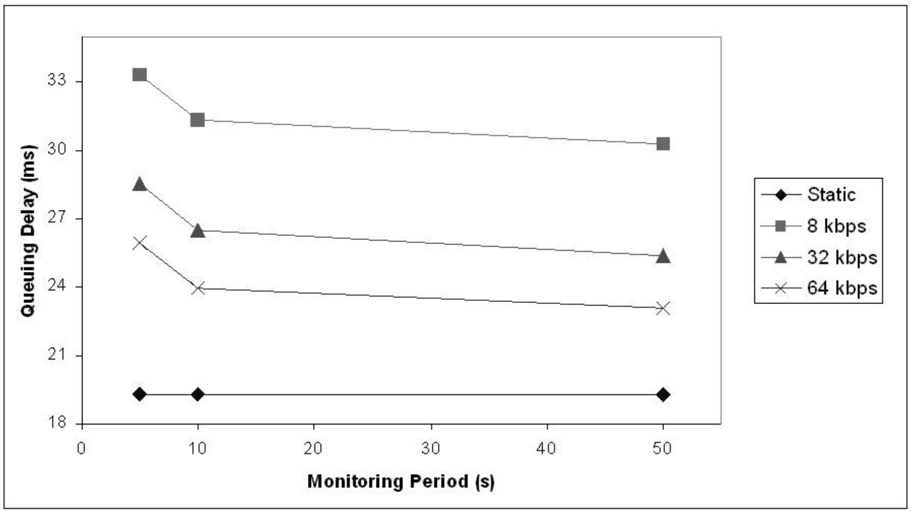

Figure 4.46. Voice Circuit Queuing Delay Comparison — System Underload

high, the reason for them lies once again in the circuit sequencing issue discussed in Section 4.6.1.2. That section also discusses two ways to alleviate the problem, each of which is a viable solution. Overall, the work conservation feature resulted in much lower queuing delays for the voice circuit. Using the worst DBA-3 configuration and the highest offered load, queuing delays were still 80.1% lower than that of the static assignment TDM model. Furthermore, the best DBA-3 configuration could still result in acceptable end-to-end delays based on the recommendation of [ITU96] even with the circuit sequencing problem.

Average queuing delay trends based on allocation granularity were similar to that observed on the data circuits. The rationale for these results is the same (cf., Section 4.6.2.2.2) since queuing delays are affected by the allocations made to/from the voice circuit. Additionally, queuing delay tended to decrease as monitoring period increased because the fewer reallocations produced a more stable environment for the voice circuit. With the Voice and Data Overload workload, however, queuing delay increased as monitoring period increased. This is most likely because of the lack of responsiveness to voice circuit demands at such high loading and infrequent update intervals. Average queuing delays are much lower at the 5.0 and 10.0 second

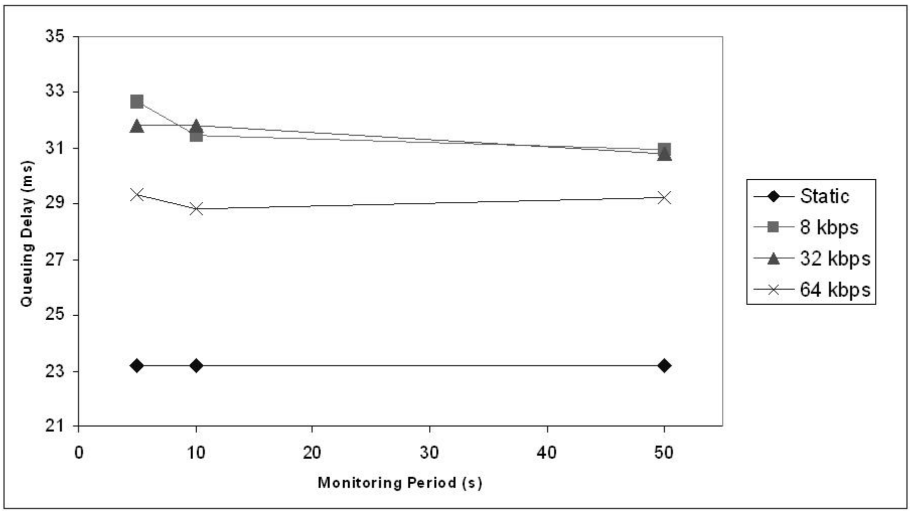

Figure 4.47. Voice Circuit Queuing Delay Comparison — Voice Overload

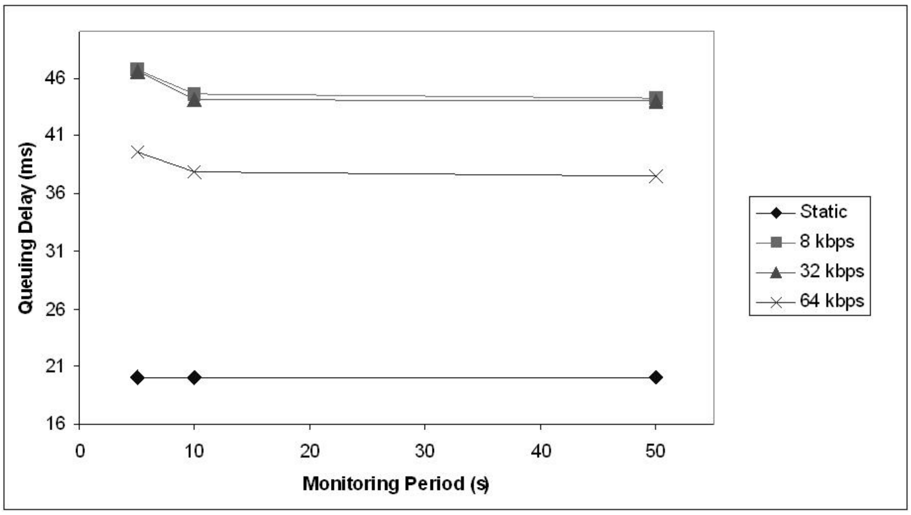

Figure 4.48. Voice Circuit Queuing Delay Comparison — Data Overload

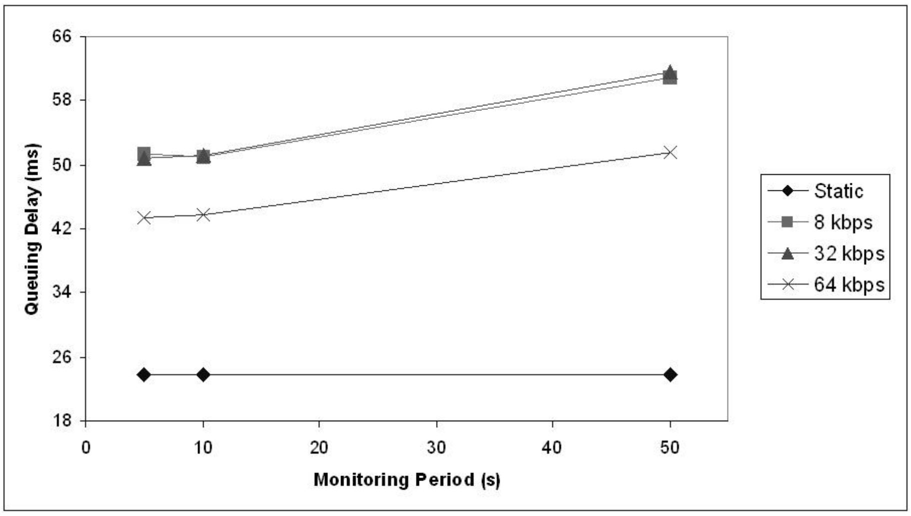

Figure 4.49. Voice Circuit Queuing Delay Comparison — Voice and Data Overload

monitoring periods indicating a better system responsiveness at this higher loading level.

4.6.2.2.4 Allocation of Variation. Workload was the single biggest contributor to the observed queuing delay variation in all four circuits, ranging from 96.97% on the video circuit down to 86.14% on the voice circuit as shown in Tables 4.6 through 4.9. This result is not surprising. With the work conservation feature employed, the number of potentially empty time slots that can be filled by other circuits goes down as the offered load to each circuit increases resulting in higher queuing delays.

Table 4.6. Voice Circuit Allocation of Variation using the DBA-3 Algorithm

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Error
86.14%	6.67%	0.57%	1.61%	4.63%	0.29%

Each circuit was only minimally affected by allocation granularity. The voice circuit was affected the most with an observed variation of 6.67%. The reason for the higher variation on the voice circuit is most likely because the voice circuit must be

Table 4.7. Video Circuit Allocation of Variation using the DBA-3 Algorithm

Var Due to Workload	Var Due to Error
96.97%	2.16%

Table 4.8. NIPRNET Circuit Allocation of Variation using the DBA-3 Algorithm

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Error
94.28%	2.76%	0.39%	1.78%	0.38%

allocated in chunks of at least 32768 bps — the necessary bandwidth for one phone call. Consequently, an 8192 bps allocation granularity did not benefit the voice circuit like it did the other circuits resulting in higher queuing delays. Allocation granularity only accounted for 2.76% and 2.90% of the observed variation on the two respective data circuits and a statistically negligible amount on the video circuit. These results indicate that, regardless of the DBA-3 configuration, queuing delay on these circuits is affected very little by anything other than the offered load.

The voice circuit was also affected by the combination of workload and monitoring period. The observed variation for this combination was 4.63%. When monitoring period was long on all but the highest loading condition, it provided the voice circuit a more stable environment since bandwidth reallocations weren't occurring as frequently. On the highest loading condition, the voice and data circuits were both heavily loaded, which meant that the system wasn't responding fast enough to system dynamics with a 50.0 second monitoring period. However, monitoring

Table 4.9. SIPRNET Circuit Allocation of Variation using the DBA-3 Algorithm

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Error
94.54%	2.90%	0.48%	1.57%	0.37%	0.05%

period did not account for much variation on its own — only 0.57% due to the circuit sequencing issue discussed in Section 4.6.1.2. As the workload increased, the sequencing issue affected the number of "extra" time slots, which combined with the stability provided by longer monitoring periods to produce this noticeable variation in the data.

Monitoring period had a negligible effect on the observed variation of each circuit. In all but the video circuit's case, the monitoring period explained only slightly more of the variation than the unexplained. The monitoring period's effect on the video circuit was less than that of the unexplained variation. These results indicate that since queuing delays have been judged acceptable under the DBA-3 algorithm, any monitoring period between 5.0 and 50.0 seconds will result in acceptable queuing delays for the system.

4.6.2.2.5 Best Configuration. The 65536 bps allocation granularity and the 10.0 second monitoring period resulted in the lowest queuing delays for the DBA-3 system. Figures 4.50 through 4.53 compare the queuing delays experienced by each circuit under each loading level for both the static and dynamic allocation methods. The 65536 bps allocation granularity produced the lowest queuing delays for the same reason as with the DBA-1 algorithm. The larger granularity resulted in fewer reallocations which resulted in fewer input buffer backups. Refer to Section 4.4.2.5 for more detail. The 10.0 second monitoring period performed better than the 5.0 and 50.0 second periods for opposite reasons. It performed better than the 50.0 second monitoring period because the 50.0 second period could not react fast enough to the dynamics of the system. The 50.0 second period reacted much slower to a sudden increase in workload for a particular circuit, which caused increased queuing delays. The 5.0 second period, on the other hand, resulted in too many reallocations. Therefore the system could not stabilize as much as with the 10.0 second monitoring period. This result is different from that using the DBA-1 algorithm, which produced the lowest queuing delays with the 5.0 second monitoring

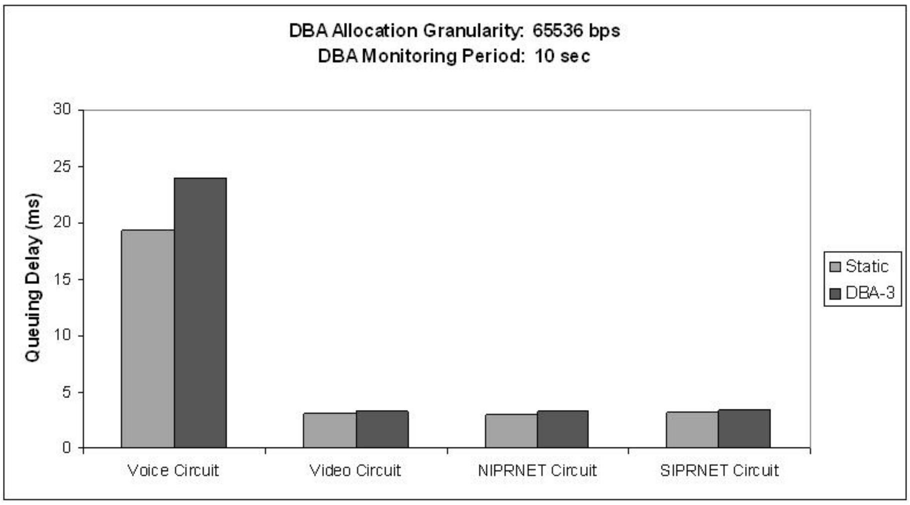

Figure 4.50. Comparison of Static and DBA-3 Queuing Delays — System Underload

period. The reason is due to the addition of the work conservation feature. Using the DBA-1 algorithm, it was important for the system to reallocate as often as possible to prevent input buffer back-up. With the work conservation feature employed, however, the system could almost always draw from potentially unused time slots to help keep queuing delay low. Therefore, the bandwidth manager does not have to reallocate as often resulting in a more stable system.

4.6.2.2.6 Data Traffic Analysis. The use of the exponential distribution to model inter-arrival times of data frames yields comparable results for "generic" bursty data models (cf., Section 4.4.3). To analyze data traffic performance more completely, however, performance must be judged across a range of burstiness "shapes". This is easily done using the Pareto distribution. Therefore, the NIPRNET and SIPRNET circuits submitted offered loads with Pareto inter-arrivals and shape parameter values between 1.1 and 1.9. This range was chosen because the variance for the Pareto distribution is infinite between 1.0 and 2.0 [Jai91]. As Figures 4.54 and 4.55 show, observed mean queuing delays on all workloads are close to that observed using exponential inter-arrivals with the exception of parameter

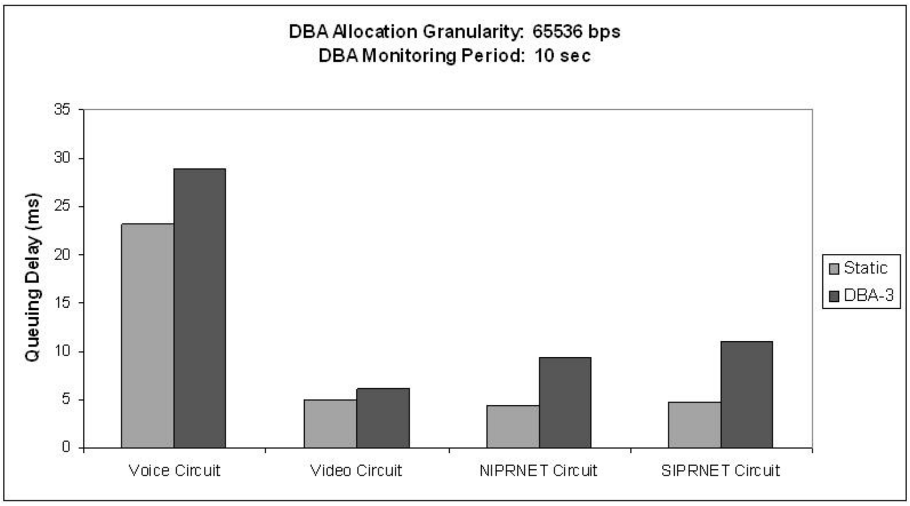

Figure 4.51. Comparison of Static and DBA-3 Queuing Delays — Voice Overload

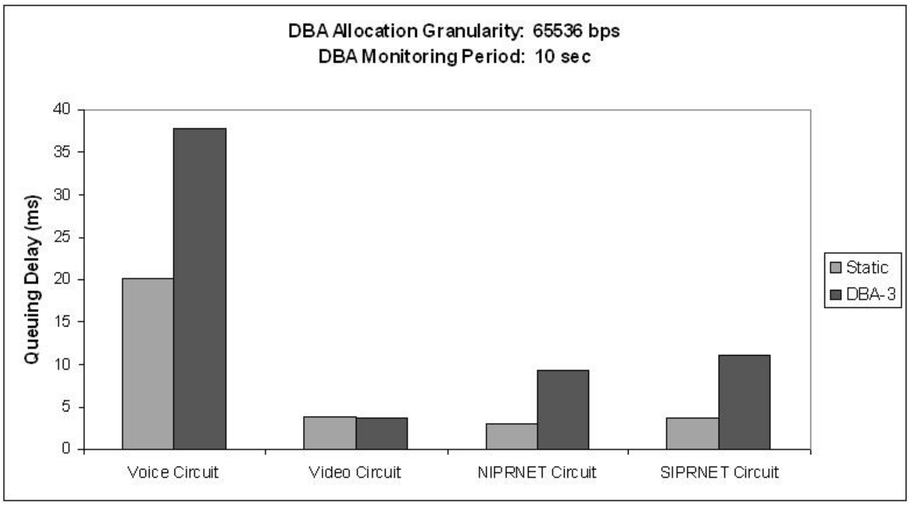

Figure 4.52. Comparison of Static and DBA-3 Queuing Delays — Data Overload

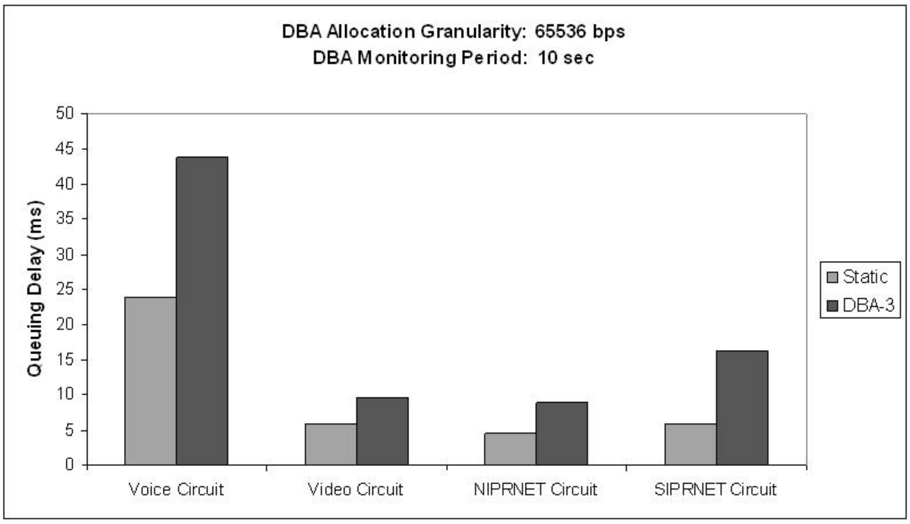

Figure 4.53. Comparison of Static and DBA-3 Queuing Delays — Voice and Data Overload

value of 1.1. The largest mean difference observed on shape values other than 1.1 was 1.38 ms on the NIPRNET circuit and 8.94 ms on the SIPRNET circuit with a Voice and Data Overload workload.

The higher queuing delays observed using a shape value of 1.1 are caused by the much wider variation of inter-arrival times at this value. Higher variation in the inter-arrival times results in more adjustments by the bandwidth manager, which results in higher queuing delays due to increased jitter. Although the mean queuing delays are higher for this shape value, queuing delays were still reasonable for data traffic. The largest mean queuing delay observed at 90% confidence was 16.21 ms on the NIPRNET circuit and 33.03 ms on the SIPRNET circuit with a Voice and Data Overload workload. This compares to mean queuing delays of 8.89 ms and 16.21 ms on the two respective data circuits using exponential inter-arrivals. Refer to Appendix B for observed values and confidence intervals.

4.6.3 Overall Assessment of the DBA-3 Algorithm. Classic queuing theory states that utilization and delay are opposing metrics [Jai91, SAH94]. In other words, at some point one metric must be sacrificed to produce significantly better results

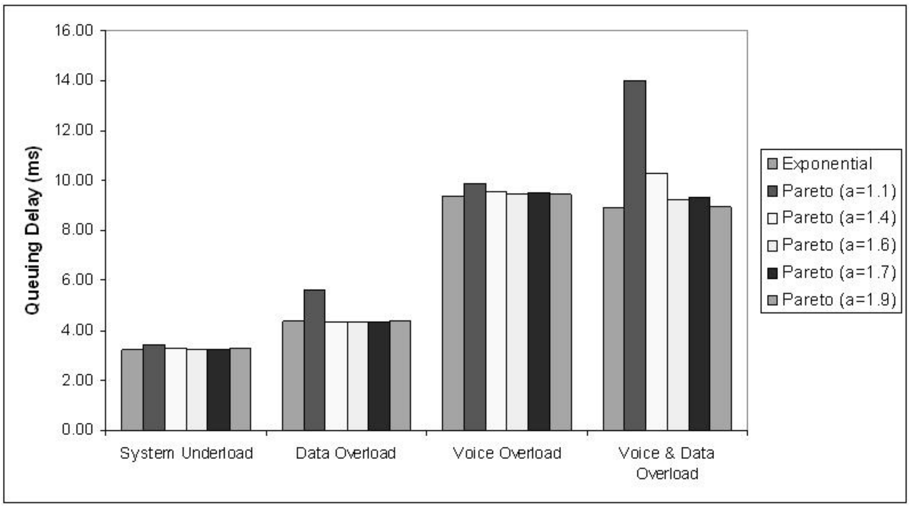

Figure 4.54. Comparison of NIPRNET Circuit Queuing Delays Based on Burst Shape

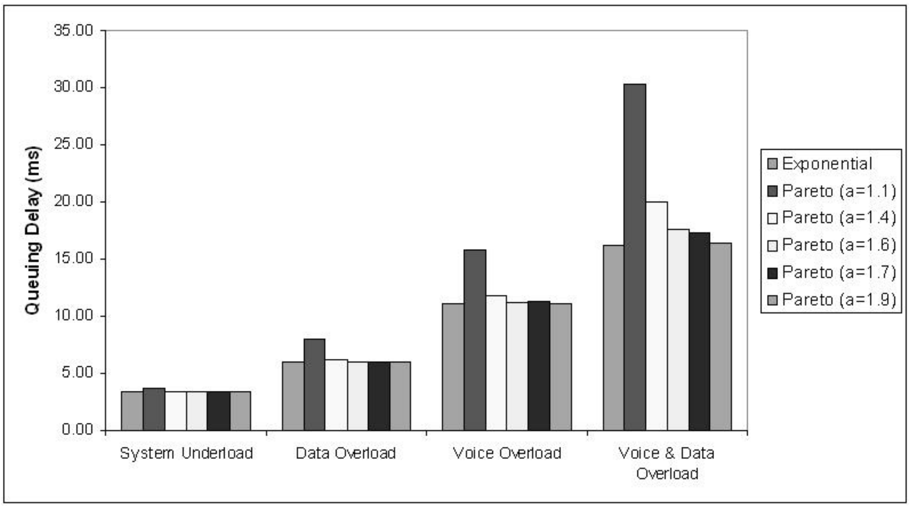

Figure 4.55. Comparison of SIPRNET Circuit Queuing Delays Based on Burst Shape

in the other. Unfortunately, utilization is usually sacrificed to keep delay low to allow networks to support real-time traffic such as voice or video. Such is the case with dynamic bandwidth allocation. Therefore, the best overall configuration of the DBA-3 algorithm consists of the 65536 bps allocation granularity and 10.0 second monitoring period. This configuration was chosen over the 32768 bps granularity and 5.0 second monitoring period because average utilization across all workloads was only 1.5% lower and queuing delay was the lowest of all configurations.

Under the chosen configuration and all submitted workloads, queuing delay was low enough to meet the accepted delay requirement for real-time traffic and utilization was increased significantly over that of the static model. Therefore the static and dynamic systems were then subjected to approximately 70%, 85%, and 99% of capacity offered loads to determine how they performed under extreme conditions. In all cases, both systems' aggregate utilizations were only negligibly different from that submitted to it.

Queuing delays increased dramatically starting at the 70% loading level for both systems as shown in Figures 4.56 through 4.59. The queuing delay increases much faster in the dynamic system because the algorithm is still adjusting the bandwidth where possible, but minor changes in circuit activity have much more drastic effects at higher loading levels. The queuing delay increase tapers off after the 85% level (and in some cases decreases) because the system is much closer to being on continuously (i.e., having very few time slots available for reallocation).

The system can still operate at this level, however, assuming no other congestion is encountered on the path from source to destination. Except for the voice circuit, the worst average queuing delay observed using DBA-3 was 106.9 ms on the SIPRNET circuit at 99% loading, shown in Figure 4.59. If other nodes are experiencing similar congestion, however, real-time traffic would probably experience unacceptable delay. Figure 4.56 shows that the sequencing problem created delays as large as 384 ms on the voice circuit. However, implementing one of the two solutions

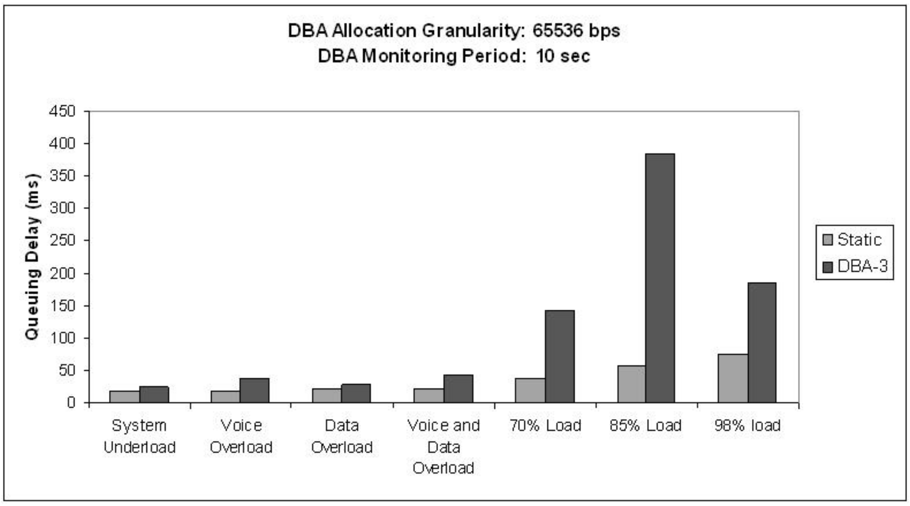

Figure 4.56. Comparison of Static and DBA-3 Queuing Delays on the Voice Circuit

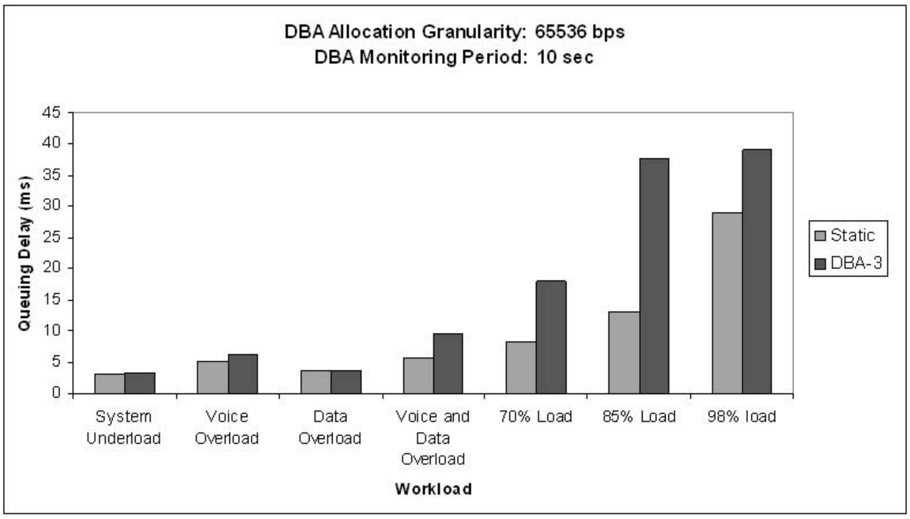

Figure 4.57. Comparison of Static and DBA-3 Queuing Delays on the Video Circuit

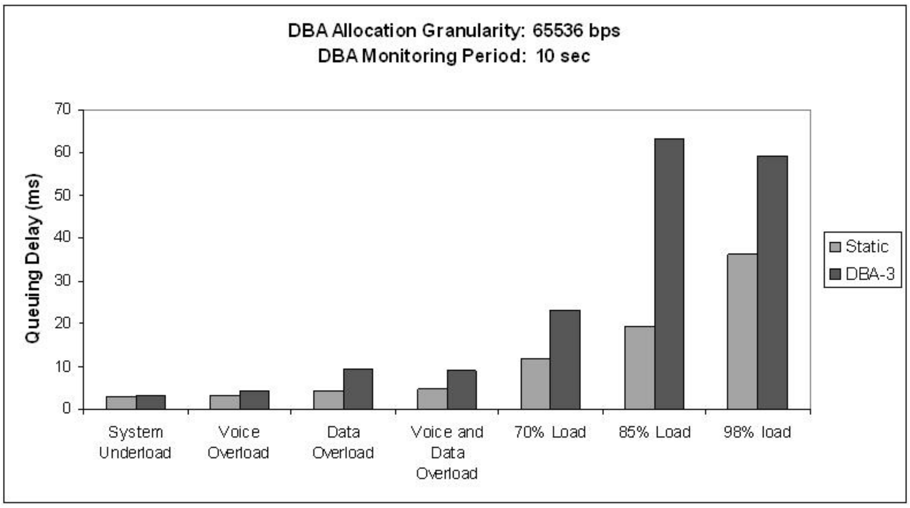

Figure 4.58. Comparison of Static and DBA-3 Queuing Delays on the NIPRNET Circuit

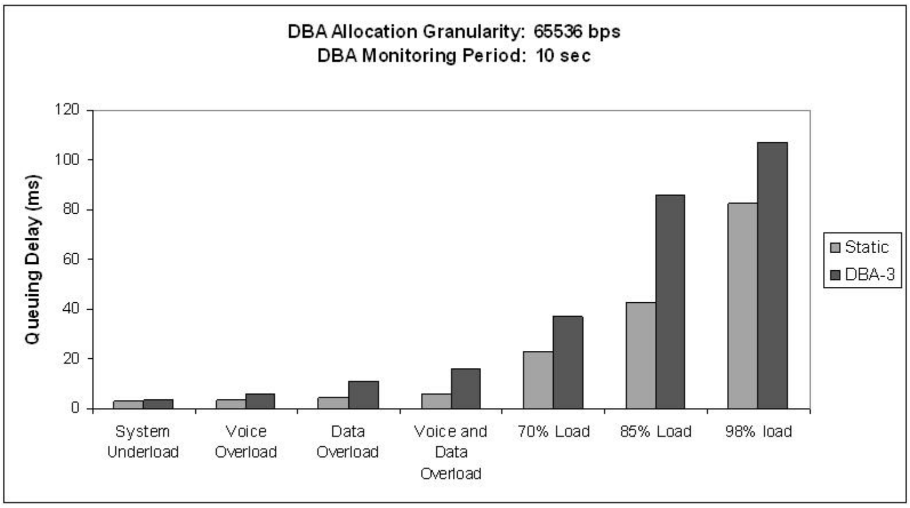

Figure 4.59. Comparison of Static and DBA-3 Queuing Delays on the SIPRNET Circuit

described in Section 4.6.1.2 should mitigate this excessive queuing delay, bringing it to an acceptable level. Furthermore, extreme loading conditions such as these should rarely occur. The Voice and Data Overload represented heavy loading of voice and data circuits but extremely low loading of the video circuit. This assumes that a video teleconferencing circuit is rarely used more than an hour per day in a tactical military environment. This usage level must reverse itself (i.e., rarely inactive for more than an hour per day) in order for near capacity loading levels to be observed. Second, the offered load on the voice circuit ceases to represent normal voice communication as observed in [CPR96] above the 70% loading level. Therefore it is reasonable to assume that extreme loading conditions such as these could only occur for a short period of time, which should only minimally disrupt communications traffic by increasing delay. Under the chosen configuration, then, the DBA algorithm with CBR priority and work conservation (DBA-3) keeps queuing delay sufficiently low while significantly increasing aggregate utilization.

4.7 Chapter Summary

This chapter described the implementation of the dynamic bandwidth allocation (DBA) algorithm in a TDM system. It further provided the DBA simulation results and compared DBA performance to the static allocation method. The DBA-1 algorithm did significantly increase utilization compared to the static system, but queuing delay was too excessive to support real-time traffic under moderate to high loading conditions. A CBR priority feature was then added to the algorithm (DBA-2) to lower queuing delays on the video circuit. While the queuing delays did decrease, it was determined that even static allocation queuing delays would be too excessive for real-time traffic when considering end-to-end delay. Therefore a work conservation feature was added (DBA-3) to both the static and dynamic allocation methods. This resulted in much lower queuing delays for both systems without decreasing the utilization gains achieved by the DBA-1 algorithm. Queuing delays for the DBA-3 algorithm were consistently higher than that of the static system but still produced results capable of supporting real-time traffic even under extreme workloads. The final conclusion is that the DBA-3 system achieves higher utilizations under all offered loads while keeping queuing delay sufficiently low.

V. *Conclusions and Recommendations*

This chapter summarizes the research presented in the first four chapters. First, an overview of the problem is presented. Then, the algorithm is described including a summary of previous research and the modifications yielding an improved solution. Conclusions are drawn based on results of the experiments. Finally, the chapter concludes with recommendations for future research.

5.1 The Problem

Military communications networks typically employ a gateway multiplexer to aggregate all communications traffic onto a single link. These multiplexers typically allocate bandwidth statically using TDM. When a high-bandwidth circuit, e.g., a VTC circuit, is relatively inactive, a considerable portion of the bandwidth is wasted. Dynamic bandwidth allocation reclaims unused bandwidth from circuits with low utilization and reallocates it to a circuit with high utilization without adversely affecting queuing delay.

5.2 Results

The proposed DBA algorithm produced outstanding results. Average utilization gains were as high as 19.95% and most configurations produced queuing delays acceptable for real-time traffic despite the 50% increase over static system queuing delays. In order to meet acceptable delay requirements described in [ITU96], two important features were incorporated into the DBA algorithm. First, because of the low loading levels and high bandwidth requirements, the algorithm immediately allocates the necessary number of time slots to the video circuit upon arrival of a video frame. Second, because static assignment TDM results in many unused time slots which cause high queuing delays, a work conservation feature is incorporated. This feature allows waiting frames from other circuits to be inserted in empty time slots.

The combination of these features was shown to drastically reduce queuing delays. In fact, queuing delays were up to two orders of magnitude lower than with the DBA algorithm without these two features. However, the voice and data circuits' queuing delays were statistically higher than the static system under all configurations and loading levels. The video circuit's queuing delays were only statistically higher on the Voice Overload and Voice and Data Overload workloads. Because the DBA algorithm's work conservation feature decreased queuing delays so dramatically, however, end-to-end delays would still be acceptable using the DBA algorithm. The system was also tested under extreme loading conditions. While queuing delay results were not impressive, end-to-end delay would probably still be within accepted limits. Utilization was unhindered by the introduction of the work conservation feature because only empty time slots were reallocated to other circuits.

Based on simulation results, the system performed best with a 65536 bps allocation granularity and 10.0 second monitoring period. This configuration minimized queuing delays while still achieving high utilization gains. Monitoring periods shorter than 10.0 seconds caused too many reallocations and created jitter. For periods longer than 10.0 seconds, the algorithm reacted too slowly to system dynamics causing excessive buffer sizes and queuing delays. Allocation granularity should be high to minimize the number of reallocations. Fewer reallocations result in more system stability, smaller buffer sizes, and lower queuing delays. Utilization was consistent under all configurations since monitoring period and allocation granularity account for less than 1% of the observed variation.

5.3 Conclusions

By including the CBR priority and work conservation features, the proposed DBA algorithm outperforms the static allocation model in all cases. By using DBA, tactical military communications networks can bring information to the warfighter more efficiently and in a shorter time in spite of small satellite bandwidths allocated to deployed sites. The proposed algorithm delivers acceptable queuing delays independent of the traffic characteristics. Real-time applications such as voice or video perform well enough to meet accepted end-to-end delay standards and data applications suffer reasonable queuing delays independent of the burstiness of arrivals. The proposed DBA algorithm now supports heterogeneous permanent circuits on a TDM platform — the typical model for the military's tactical communications networks. Furthermore, the algorithm can be completely implemented in software with little or no additional hardware significantly reducing implementation costs. The algorithm is general enough to be applied to multiple TDM platforms, including NET's Promina — the military's primary gateway multiplexer. Additionally, the algorithm is robust enough to function at any speed making it a viable option for high-speed multiplexers. The proposed DBA algorithm is a powerful tool for optimizing use of available communications network resources.

5.4 Recommendations

Although the developed DBA algorithm is robust and powerful, it is not without limitations or questions to be answered. First, and most important, it is unknown how much delay is caused by the algorithm's calculations. The simulation tool used, OPNET Modeler [OPN01], uses state-transition diagrams to describe a process or model. All processing done during the entrance/exit to/from a state occurs while the simulation clock is stopped. It is unlikely that the instantaneous utilization calculations and subsequent reallocations cause undue delay, but this assumption should be verified.

Second, the circuit sequencing issue described in Section 4.6.1.2 should be resolved. Two solutions were presented — prioritizing the circuits so that real-time traffic has a higher priority on unused time slots and randomly selecting a circuit to fill an unused time slot. It was shown in Chapter 4 that the system produced acceptable delays, but resolving the circuit sequencing issue should reduce queuing delays, yielding even better performance. It is also unknown which proposed solution would work best. For instance, if there were multiple voice circuits, the proposed circuit prioritization might not provide optimal results. Conversely, randomly choosing a circuit to fill an unused time slot might result in excessive delay due to processing overhead.

Third, since military communications networks' gateway multiplexer function is performed by NET's Promina, a more accurate model of this system is needed. Currently available literature on the Promina leaves many questions unanswered. For example, the framing format and size are unknown which affects the service rate of the system. The frame's header format is also unknown which means that it is unknown whether each frame carries a circuit identifier. If it does not, then this DBA algorithm may not be feasible for this platform without a fundamental modification to the system. Input buffer sizes are also unknown, which affect both queuing delay and frame loss rate. These issues would need to be addressed before judgment can be made on the viability of porting this algorithm to this platform at a low cost.

Finally, the system boundary for this study contained only a single multiplexer. Thus delivery rates, coordination of bandwidth reallocation between adjacent nodes, and end-to-end delay were not addressed. Further research should be done to determine whether end-to-end delay in a communications network including a satellite connection is acceptable while employing this DBA algorithm.

5.5 Chapter Summary

This chapter summarized the research into dynamic bandwidth allocation in a TDM environment. Based on the results of the study, it was concluded that this algorithm can greatly optimize the use of limited bandwidth for a low upgrade cost. Recommendations for future work were also provided, which, if explored, would produce an algorithm more powerful and robust than this one has already proven to be.

Appendix A. Model Verification and Validation

A.1 Time-Division Multiplexing Scheme

Time-Division Multiplexing (TDM) is a method of aggregating information from one or more user circuits onto a single aggregate link. Using TDM, each circuit is allocated a specific amount of the aggregate link's bandwidth and each circuit's allocation is divided into one or more time slots. When a circuit's assigned time slot occurs, the multiplexer forwards a packet if one is available and goes empty if not. In the model employed in this study, each time slot was capable of servicing one 4096-bit packet and each circuit's time slots were allocated contiguously (i.e., all of Circuit 0's time slots occur, then all of Circuit 1's, etc.).

A.2 Static Allocation Validation

A.2.1 1 Circuit.

A.2.1.1 Workload and Utilization. The circuit was configured with the parameter values given in Table A.1. As Figure A.1 shows, with only one circuit, instantaneous utilization was at 100% during the ON period and 0% during the OFF period, as expected.

A.2.1.2 Queuing Delay. A synchronous time-division multiplexer with 1 Circuit acts like a D/D/1 queue with an arrival rate of λ = 16384 bps = 4

Table A.1. Single Circuit Parameter Values

Parameter	**Value**
Circuit Type	ON/OFF Source
ON Period Distribution	Constant
ON Period Duration	1800 sec
OFF Period Distribution	Constant
OFF Period Duration	1800 sec
Data Rate	16384 bps

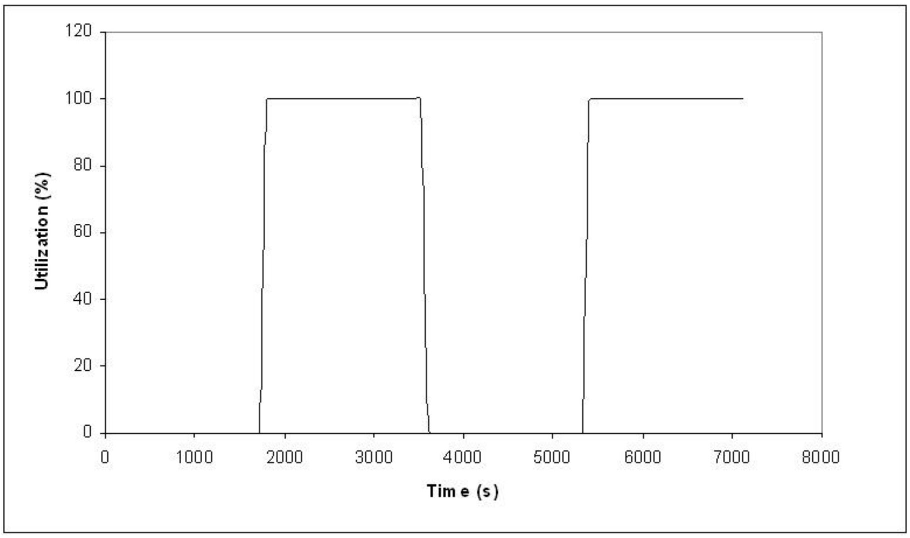

Figure A.1. Single Circuit Utilization — Static Allocation Method

pps and a service rate of $\mu = 16384$ bps $= 4$ pps. This yields an expected utilization of

$$\rho = \frac{\lambda}{\mu} = \frac{4}{4} = 1 \tag{A.1}$$

where ρ is the utilization. The expected number in service, n_{svc}, is

$$E(n_{svc}) = \rho = 1. \tag{A.2}$$

Because of the synchronous nature of the system, a new packet arrives as one finishes service. Therefore, E(n_q) = 0 and E(w) = 0, where E(n_q) is the expected number in the queue, and E(w) is the expected waiting time. The expected service time, E(s), and time in system, E(r), are

$$E(s) = \frac{1}{\mu} = 0.25 \text{ sec} \tag{A.3}$$

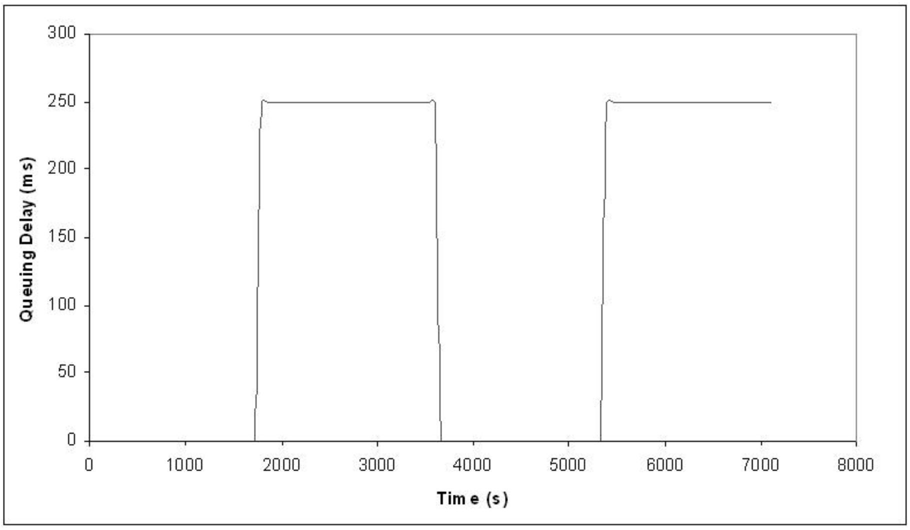

Figure A.2. Single Circuit Queuing Delay — Static Allocation Method

Table A.2. Two-Circuit Configuration Parameter Values

Circuit 0		**Circuit 1**	
Parameter	**Value**	**Parameter**	**Value**
Circuit Type	ON/OFF Source	Circuit Type	ON/OFF Source
ON Period Distribution	Constant	ON Period Distribution	Constant
ON Period Duration	2400 sec	ON Period Duration	1800 sec
OFF Period Distribution	Constant	OFF Period Distribution	Constant
OFF Period Duration	1200 sec	OFF Period Duration	1800 sec
Data Rate	16384 bps	Data Rate	16384 bps

$$E(r) = E(w) + E(s) = 0 + 0.25 = 0.25 \text{ sec for 1 circuit} \tag{A.4}$$

This result matches exactly the results obtained via simulation (see Figure A.2).

A.2.2 2 Circuits.

A.2.2.1 Workload. The circuits were configured with the parameter values given in Table A.2. This resulted in the offered load shown in Figure A.3.

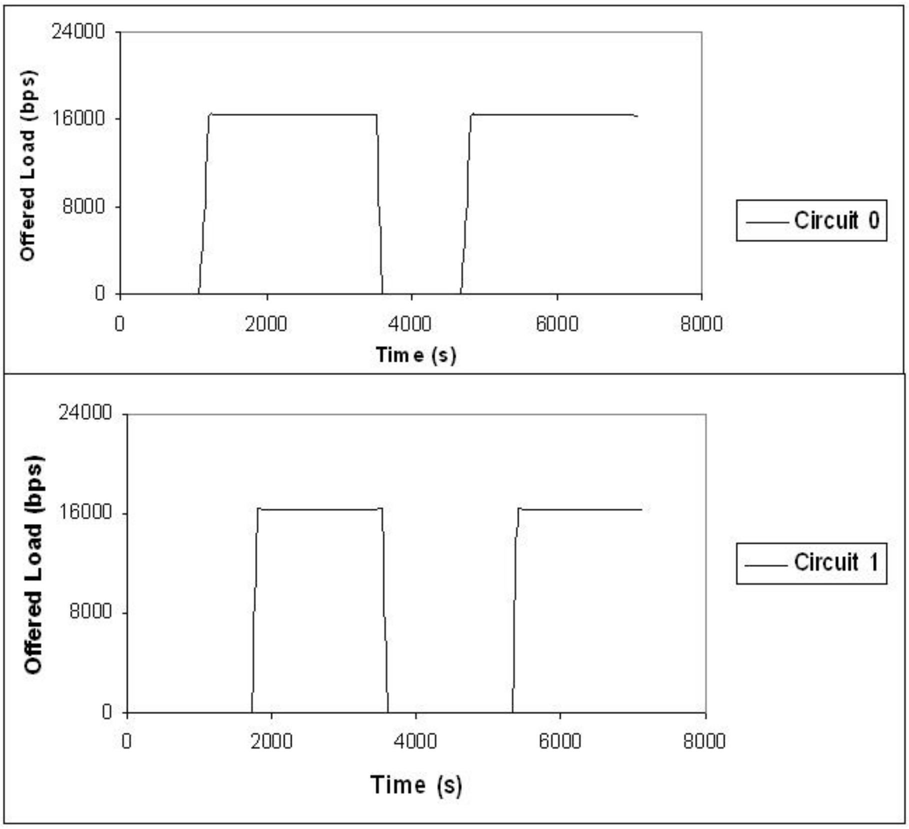

Figure A.3. Two-Circuit Configuration Workload — Static Allocation Method

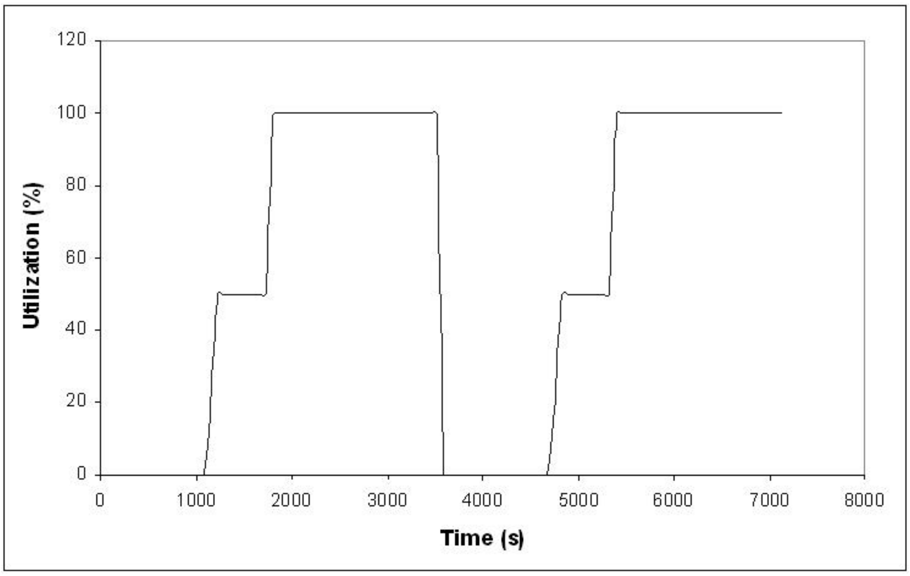

Figure A.4. Two-Circuit Configuration Utilization — Static Allocation Method

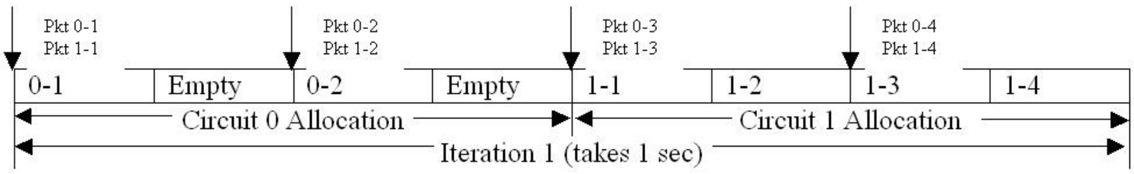

Figure A.5. Two-Circuit Configuration Time Slot Allocation — Static Allocation Method

A.2.2.2 Utilization. As expected, instantaneous utilization was at 50% when Circuit 0 was the only active circuit, 100% when both circuits were active, and 0% when neither circuit was active. Figure A.4 confirms these results.

A.2.2.3 Queuing Delay. Figure A.5 depicts the packet arrivals and time slot allocations for the first and subsequent TDM iterations. It also depicts the packet servicing of the first TDM iteration. If $\lambda = 8$ pps and $\mu = 8$ pps, then the expected service time is as shown in Equation A.5.

$$E(s) = \frac{1}{\mu} = 0.125 \text{ sec} \tag{A.5}$$

A.2.2.3.1 Packet Arrivals. Each circuit's arrival rate is 4 pps, yielding an aggregate arrival rate of 4 * 2 = 8 pps. Packets arrive synchronously and two will arrive (one from each circuit) every 0.25 sec. Each arriving packet will be queued up in a subqueue designated for that circuit until it can be serviced. Thus, two packets arrive at times 0, 0.25, 0.50, 0.75, 1.0, etc. In the diagram above, these packet arrivals are designated by the convention Pkt Ckt# - Pkt#. For example, Pkt 0-1 represents the first packet arriving on Circuit 0 in a particular iteration, whether t = 0.0 or t = 1.0. Thus, the fifth packet to arrive from t = 0.0 will also be designated as Pkt 0-1.

A.2.2.3.2 Packet Servicing. Each circuit's data rate is 16384 bps or 4 pps. Therefore each circuit will be allotted four time slots per second. These are allocated contiguously, as shown in Figure A.5. At t = 0, Pkt 0-1, which has just arrived, can be serviced immediately. This results in a waiting time of 0 sec. Since the service time is 0.125 sec, the total time in system for Pkt 0-1 is 0 + 0.125 = 0.125 sec. At t = 0.125, Circuit 0 has no packets queued up so the time slot goes empty. At t = 0.25, Pkt 0-2, which has just arrived, can be serviced immediately. Like Pkt 0-1, this results in a total time in system of 0.125 sec. At t = 0.375, Circuit 0 has no packets queued up so the time slot goes empty.

Time t = 0.5 starts Circuit 1's time slot allocations. Circuit 1 has three packets queued up at this point (Pkts 1-1, 1-2, and the just-arrived 1-3). Pkt 1-1 is serviced at this time since it is at the head of the queue. This results in a waiting time of 0.125 sec * 4 time slots = 0.5 sec and a service time of 0.125 sec. The resulting total time in system is 0.625 sec. At t = 0.625, Pkt 1-2 is serviced. It's waiting time is 0.125 sec * 3 time slots = 0.375 sec. This results in a total time in system of 0.5 sec. At t = 0.75, Pkt 1-3 is serviced. Its waiting time is 0.125 sec * 2 time slots = 0.25 sec. The total time in system is 0.375. Finally, Pkt 1-4 is serviced at t = 0.875. Its waiting time is 0.125 sec * 1 time slot and its total time in system is 0.25 sec.

Table A.3. Two-Circuit Configuration Parameter Values

Circuit 0		**Circuits 1-4**	
Parameter	**Value**	**Parameter**	**Value**
Circuit Type	ON/OFF Source	Circuit Type	ON/OFF Source
ON Period Distribution	Constant	ON Period Distribution	Constant
ON Period Duration	2400 sec	ON Period Duration	1800 sec
OFF Period Distribution	Constant	OFF Period Distribution	Constant
OFF Period Duration	1200 sec	OFF Period Duration	1800 sec
Data Rate	16384 bps	Data Rate	16384 bps

At this point, the first iteration of time slots has passed. However, Pkts 0-3 and 0-4 have not been serviced. On the next iteration, these packets will be serviced at times 1.0 and 1.125, respectively. Their waiting times are 0.5 sec and 0.375 sec, respectively, resulting in total times in system of 0.625 and 0.5 sec. At t = 0.25, Pkt 0-1 is serviced, followed by Pkt 0-2 at t = 0.375. Their subsequent waiting times are 0.25 and 0.125 sec, with total times in service of 0.375 and 0.25 sec, respectively. Pkts 1-1 through 1-4 will be serviced in the same time slots as the last iteration and will have the same total times in system. The average total time in system for Circuits 0 and 1 is the average of each circuit and each packet's delays over time. For the two-circuit configuration, each circuit's average time in system is 0.4375 sec. This result matches exactly the results obtained via simulation as shown in Figure A.6.

A.2.3 5 Circuits.

A.2.3.1 Workload. The circuits were configured with the parameter values given in Table A.3. This resulted in the offered load shown in Figure A.7.

A.2.3.2 Utilization. As expected, instantaneous utilization was at 20% when Circuit 0 was the only active circuit, 100% when all circuits were active, and 0% when zero circuits were active. Figure A.8 confirms these results.

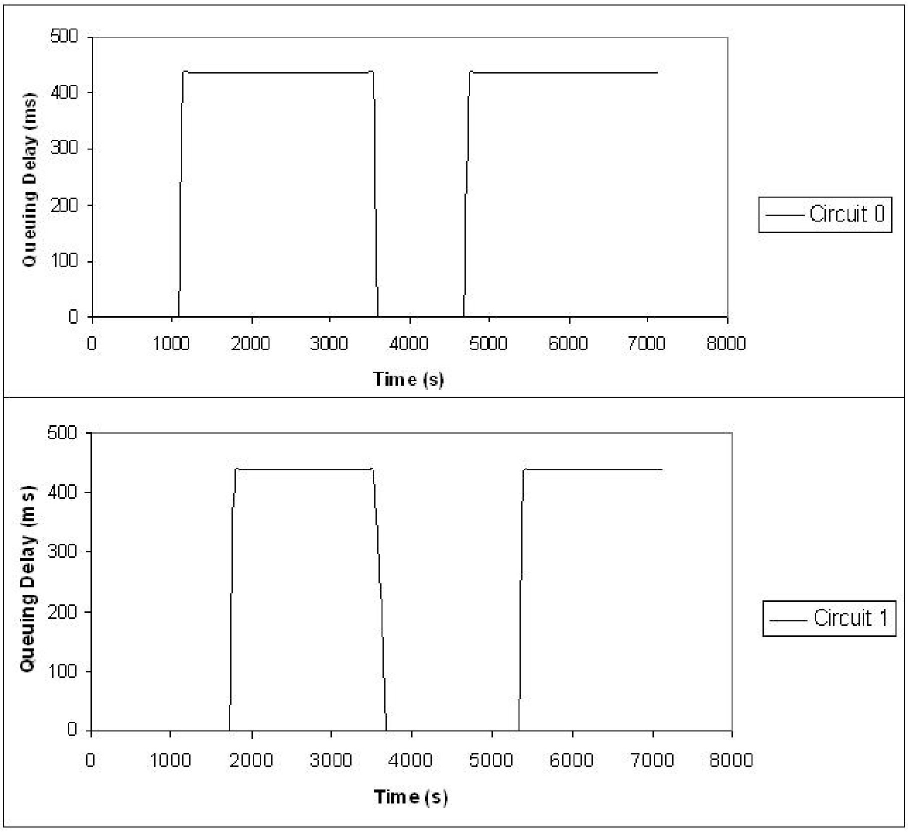

Figure A.6. Two-Circuit Configuration Queuing Delay — Static Allocation Method

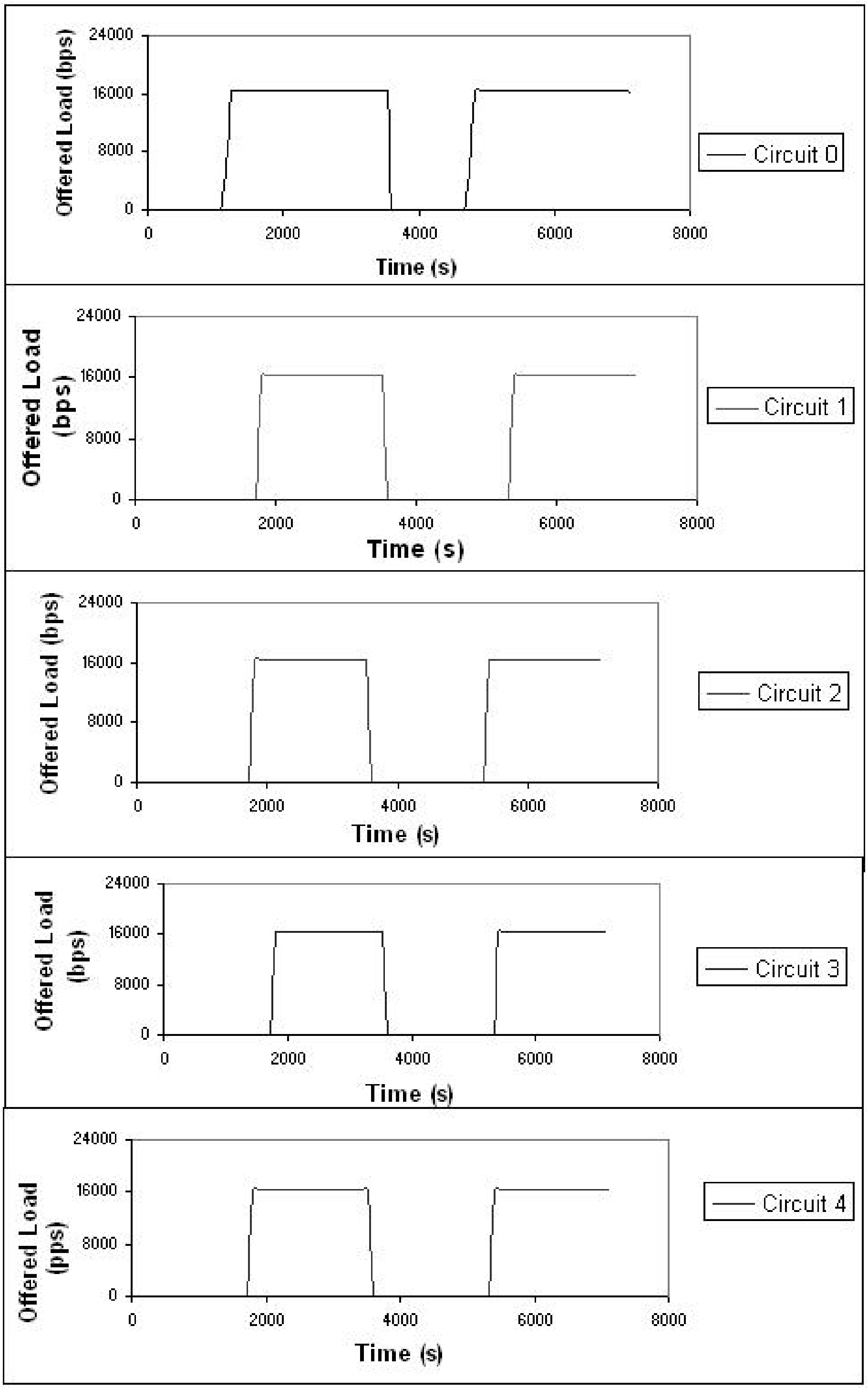

Figure A.7. Five-Circuit Configuration Workload — Static Allocation Method

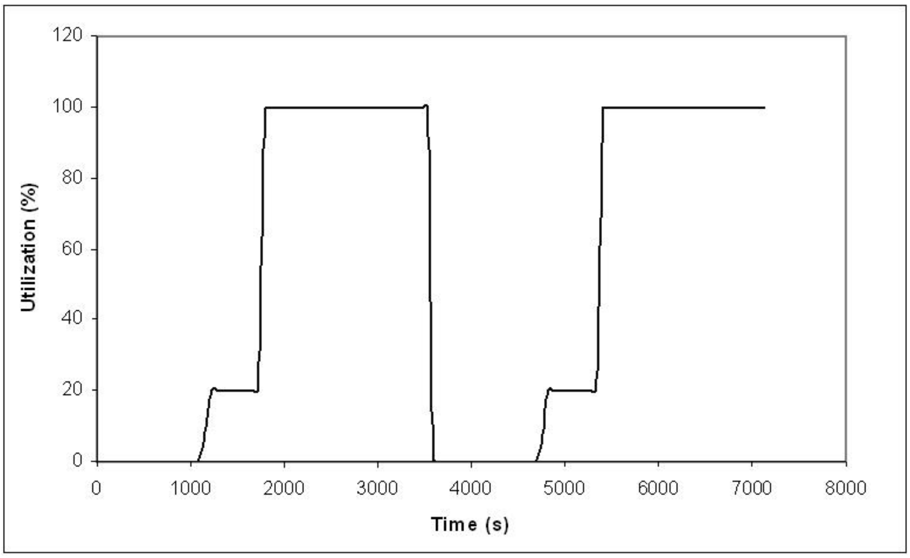

Figure A.8. Five-Circuit Configuration Utilization — Static Allocation Method

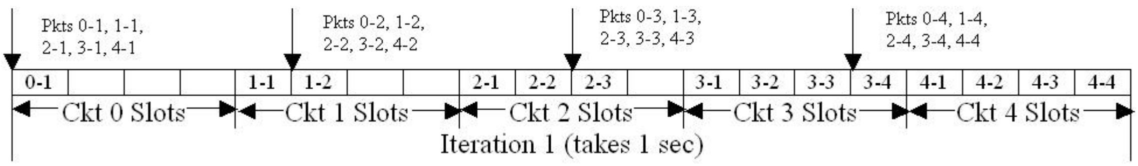

Figure A.9. Five-Circuit Configuration Time Slot Allocation — Static Allocation Method

A.2.3.3 Queuing Delay. Figure A.9 shows the packet arrivals and time slot allocations for the first and subsequent TDM iterations. It also depicts the packet servicing of the first TDM iteration. If $\lambda = 20$ pps and $\mu = 20$ pps, then the expected service time is as shown in Equation A.6.

$$E(s) = \frac{1}{\mu} = 0.05 \text{ sec} \tag{A.6}$$

A.2.3.3.1 Packet Arrivals. Each circuit's arrival rate is 4 pps, yielding an aggregate arrival rate of 4 * 5 = 20 pps. Packets arrive synchronously and five will arrive (one from each circuit) every 0.25 sec. Like the two-circuit configuration, each arriving packet will be queued up in its respective circuit's subqueue until it can be serviced. Thus, five packets arrive at times 0, 0.25, 0.50, 0.75, 1.0, etc. In the diagram above, packet arrivals are designated by the same convention as that given Section A.2.2.3.1 (i.e. Pkt Ckt#-Pkt#).

A.2.3.3.2 Packet Servicing. Like the two circuit-configuration, each circuit is allotted 4 pps, yielding four contiguous time slots per second, as shown in the diagram above. At t = 0, Pkt 0-1, which has just arrived, can be serviced immediately. This results in a waiting time of 0 sec. Since the service time is 0.05 sec, the total time in system for Pkt 0-1 is 0 + 0.05 = 0.05 sec. At times 0.05, 0.10, and 0.15, Circuit 0 has no packets queued up so the remaining three time slots go empty.

Time t = 0.20 starts Circuit 1's time slot allocations. Circuit 1 has one packet queued up at this point (Pkt 1-1). It is serviced at this time. This results in a waiting time of 0.05 sec * 4 time slots = 0.20 sec and a service time of 0.05 sec. The resulting total time in system is 0.25 sec. At t = 0.25, the just-arrived Pkt 1-2 can be serviced immediately, resulting in a zero wait time and a total time in system of 0.05 sec. At times 0.30 and 0.35, there are no packets queued up for Circuit 1 so the remaining two time slots go empty.

Time t = 0.40 starts Circuit 2's time slot allocations. Circuit 2 has two packets queued up at this point (Pkts 2-1 and 2-2). These two packets are serviced in turn, resulting in respective waiting times of 0.40 sec and 0.20 sec and respective total times in system of 0.45 sec and 0.25 sec. At t = 0.50, the just-arrived Pkt 2-3 is serviced yielding a total time in system of 0.05 sec. Circuit 2's final time slot goes empty because the queue has been emptied.

At t = 0.60, Circuit 3's time slot allocations start. Circuit 3 has three packets queued up at this time and they are serviced in turn. Their respective waiting times are 0.60 sec, 0.45 sec, and 0.20 sec. The total times in system are 0.65 sec, 0.50 sec, and 0.25 sec, respectively. At t = 0.75, the just-arrived Pkt 3-4 can be serviced immediately, resulting in a total time in system of 0.05 sec.

Circuit 4's time slots begin at t = 0.80. At this point, there are four packets queued up, so each of them are serviced in turn. This results in waiting times of 0.80 sec, 0.60 sec, 0.40 sec, and 0.20 sec, respectively, and total times in system of 0.85 sec, 0.65 sec, 0.45 sec, and 0.25 sec, respectively.

At this point, the first iteration of time slots has passed. However, Circuit 0 now has three packets queued up, Circuit 1 has two, and Circuit 2 has one. On the next iteration, Circuit 0's three queued-up packets (Pkts 0-2, 0-3, and 0-4) will be serviced at times 1.0, 1.05, and 1.10. Their waiting times are 0.75 sec, 0.55 sec, and 0.35 sec, respectively, resulting in total times in system of 0.80 sec, 0.60 sec, and 0.40 sec. At time 0.15, Pkt 0-1 is serviced. Its subsequent waiting time is 0.15 sec with a total time in system of 0.20 sec. Pkts 1-3 and 1-4 will be serviced at times 0.20 and 0.25. These packets will have waiting times of 0.70 sec and 0.50 sec, respectively, and total times in system of 0.75 sec and 0.55 sec. Pkt 2-4 will be serviced at t = 0.40. Its waiting time is 0.65 sec and its total time in system is 0.70 sec. Pkts 2-1 through 2-3 will be serviced next. Their waiting times are 0.45 sec, 0.20 sec, and 0.05 sec, with total times in system of 0.50 sec, 0.25 sec, and 0.10 sec. Pkts 4-1 through 4-4 will be serviced in the same time slots as the last iteration and will have the same total times in system. The average total time in system for each circuit is the average of each circuit and each packet's delays over time. For the five-circuit configuration, Circuit 0 through 4's respective average times in system are 0.50 sec, 0.45 sec, 0.40 sec, 0.35 sec, and 0.55 sec. This result matches exactly the results obtained via simulation as shown in Figure A.10.

A.3 Dynamic Bandwidth Allocation Validation

A.3.1 1 Circuit.

A.3.1.1 Workload and Utilization. The circuit was configured with the same parameter values as the one-circuit configuration of the static system.

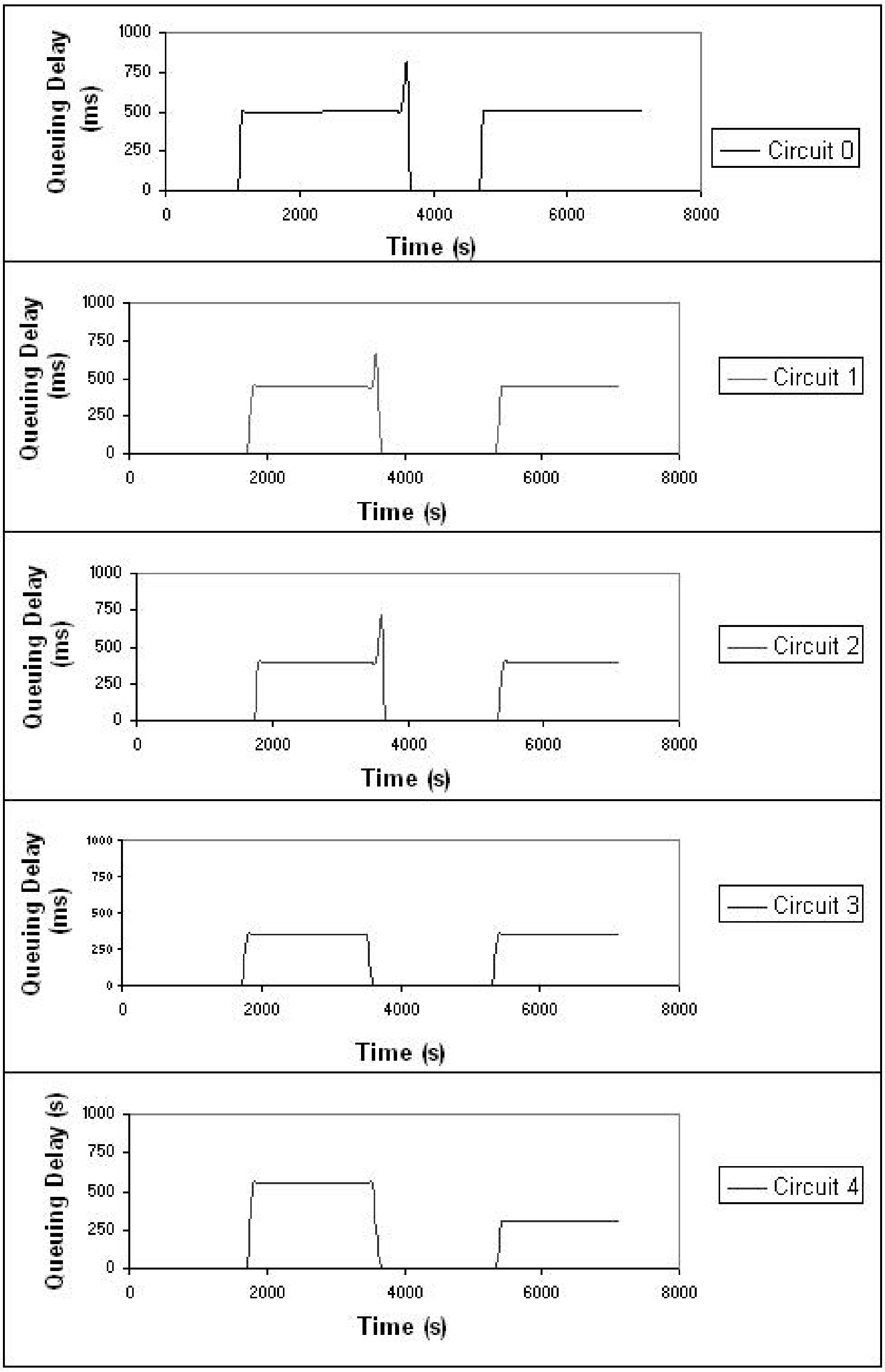

Figure A.10. Five-Circuit Configuration Queuing Delay — Static Allocation Method

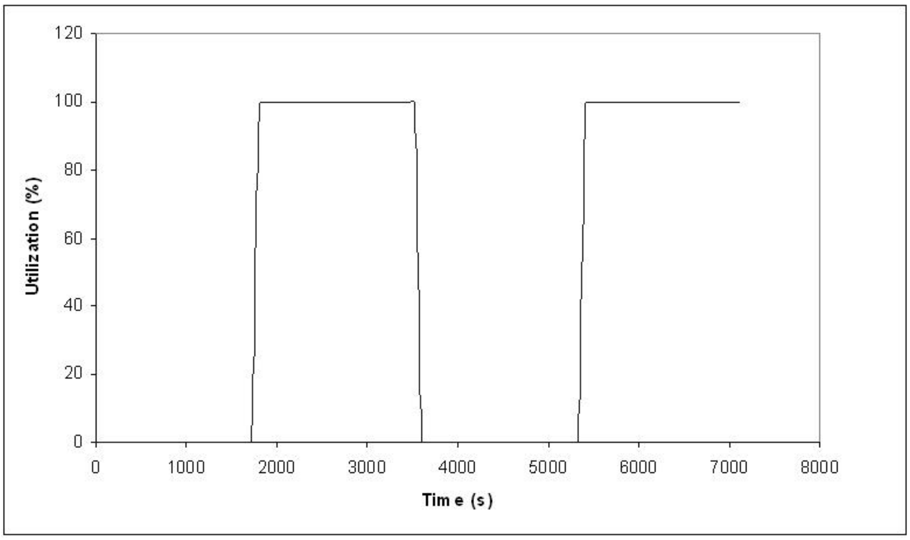

Figure A.11. Single Circuit Utilization — DBA Method

These values were given in Table A.1. As Figure A.11 shows, with only one circuit, instantaneous utilization was at 100% during the ON period and 0% during the OFF period, as expected.

A.3.1.2 Queuing Delay. Since only one circuit is connected to the mux, the system should perform exactly as the static allocation model does. Refer Section A.2.1.2 above for detailed analysis. Simulation results for this configuration match exactly that of the static allocation model (see Figure A.12).

A.3.2 2 Circuits.

A.3.2.1 Workload and Utilization. The circuits were configured with the same parameter values as the two-circuit configuration of the static system (see Table A.2). Additionally, the following assumptions were used to validate the model against the theoretical model:

- Reallocation occurs instantaneously (i.e. whenever bandwidth becomes available, it is allocated instantly). Monitoring Period is of length zero.

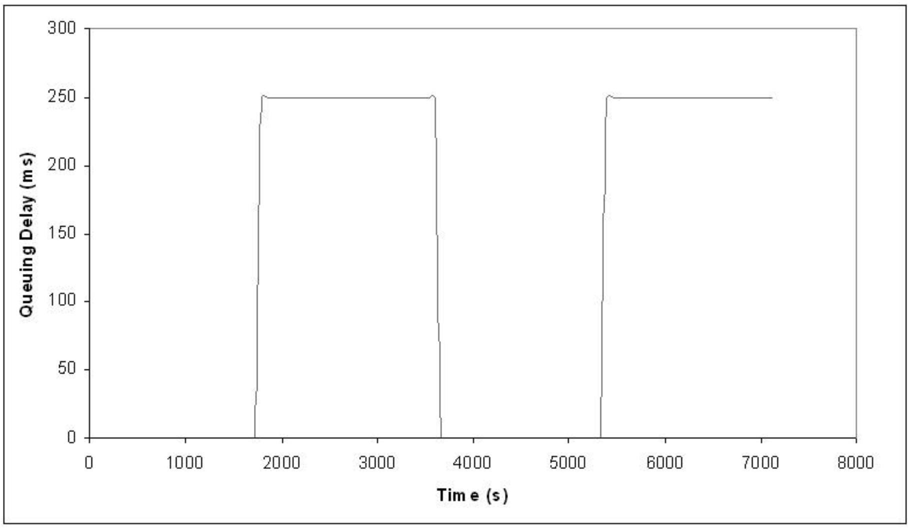

Figure A.12. Single Circuit Queuing Delay — DBA Method

- Minimum Bandwidth Level: 8192 bps

The resulting offered load and utilization are shown in Figures A.13 and A.14. At t = 0, the instantaneous utilization is 0%, as expected. At t = 1200, the instantaneous utilization is initially 50% because Circuit 0 is allocated half of the bandwidth. Immediately, Circuit 0 is allocated all but 8192 bps of Circuit 1's bandwidth, resulting in a new data rate of 24576 bps for Circuit 0. Instantaneous utilization at this point becomes 75% since Circuit 0 takes advantage of the increased bandwidth and Circuit 1 is still idle. At t = 1800, Circuit 1 becomes active and instantaneous utilization increases to 100%. Immediately, Circuit 0 reduces its bandwidth and data rate from 24576 bps to 16384 bps while Circuit 1 increases its bandwidth from 8192 bps to 16384 bps. Instantaneous utilization remains at 100% until the off period at t = 3600.

A.3.2.2 Queuing Delay. Using the workload described above with dynamic allocation, there are four possible states the system could be in, which could affect queuing delay. Three of these will be discussed in turn. The fourth occurs when neither circuit is transmitting, resulting in a zero queuing delay.

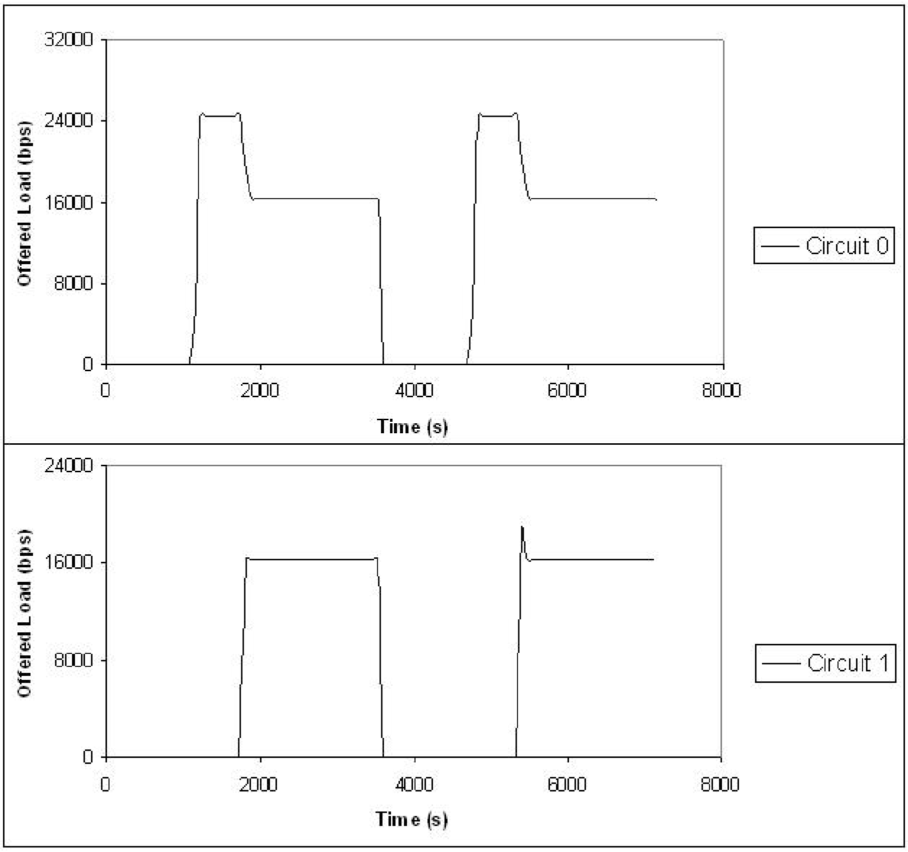

Figure A.13. Two-Circuit Configuration Workload — DBA Method

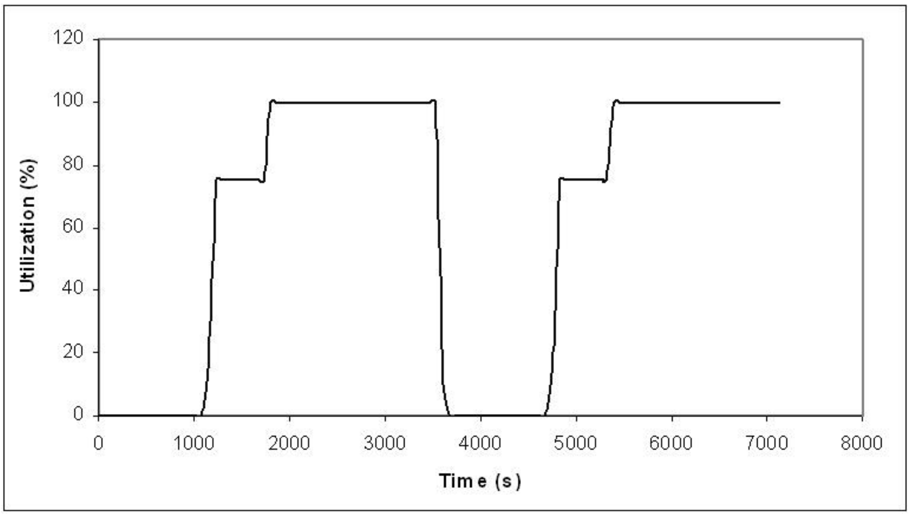

Figure A.14. Two-Circuit Configuration Utilization — DBA Method

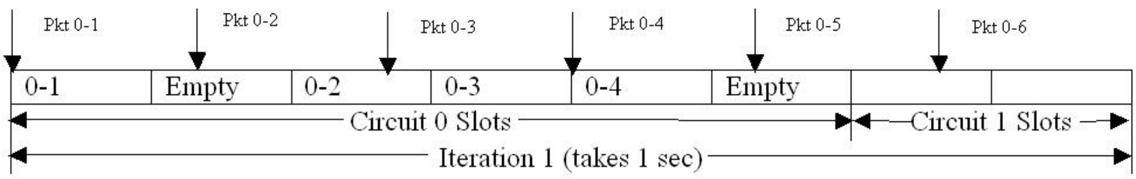

Figure A.15. Two-Circuit Configuration Time Slot Allocation — DBA Method

Circuit 0 On, Circuit 1 Off, Before Reallocation: When Circuit 0 initially becomes active, the bandwidth allocations are at the originally assigned levels. Therefore, the expected total time in system will be the same as that shown under the static model: 0.4375 sec. Note that Circuit 1's queuing delay should be zero since it is inactive at that time. It should also be noted that, under the assumption of instantaneous reallocation, this delay level would not be seen since the reallocation would occur as soon as this condition occurred.

Circuit 0 On, Circuit 1 Off, After Reallocation: Figure A.15 depicts the packet arrivals and time slot allocations for the first and subsequent TDM iterations in this configuration. It also depicts the packet servicing of the first TDM iteration. Once bandwidth is reallocated to 24576 bps and 8192 bps for Circuit 0 and 1, respectively, the time slot allocations will be as shown in the figure. If $\lambda = 6$ pps and $\mu = 8$ pps, then the expected service time is as shown in Equation A.7.

$$E(s) = \frac{1}{\mu} = 0.125 \text{ sec} \tag{A.7}$$

A.3.2.2.1 Packet Arrivals. Circuit 0's arrival rate is 6 pps; Circuit 1 is idle. Therefore, the aggregate arrival rate is 6 pps. Packets arrive synchronously and one will arrive every 1/6 of a second. Each arriving packet will be queued up in Circuit 0's subqueue until it can be serviced. In the diagram above, these packet arrivals are designated by the convention Pkt Ckt# - Pkt#. For example, Pkt 0-1 represents the first packet arriving on Circuit 0 in a particular iteration, whether t = 0.0 or t = 1.0. Thus, the seventh packet to arrive from t = 0.0 will also be designated as Pkt 0-1.

A.3.2.2.2 Packet Servicing. Circuit 0's data rate under this configuration is 24576 bps or 6 pps. Therefore, it will be allotted six time slots per second. These are allocated contiguously, as shown in the diagram. At t = 0, Pkt 0-1, which has just arrived, can be serviced immediately. This results in a waiting time of zero sec. Since the service time is 0.125 sec, the total time in system for Pkt 0-1 is 0 + 0.125 = 0.125 sec. At t = 0.125, there are no packets in the queue, so the slot goes empty. At t = 0.25, the recently-arrived Pkt 0-2 can be serviced. It's waiting time is 0.0833 sec yielding a total time in system of 0.0833 sec + 0.125 sec = 0.2083 sec. Pkt 0-3 is serviced at t = 0.375. Its waiting time and total time in system are 0.0417 sec and 0.1667 sec, respectively. At t = 0.5, the just-arrived Pkt 0-4 is serviced. Since its waiting time is zero, its total time in system is 0.125 sec. The time slot at t = 0.625 goes empty because there are no more packets queued up. Finally, the time slots at times 0.75 and 0.875 go empty because Circuit 1 is inactive.

At this point, the first iteration of time slots has passed. However, Pkts 0-5 and 0-6 have not been serviced. On the next iteration, these packets will be serviced at times 1.0 and 1.125, respectively. Their waiting times are 0.3333 sec and 0.2917 sec, respectively. The resulting total times in system are 0.4583 and 0.4167 sec, respectively. Pkts 0-1 through 0-4 will then be serviced in the next four time slots. The average total time in system for each packet will be 0.354 sec.

Circuit 0 On, Circuit 1 On, After Reallocation: At t = 1800, Circuit 1 becomes active and begins transmitting at 16384 bps. Circuit 1 will only be able to transmit half of the arriving packets during each second, however, since its slot allocation has been cut in half. Therefore, queuing delay will increase without bound as long as its assigned bandwidth is only 8192 bps. Since the theoretical model assumes instantaneous reallocation, though, this problem will never occur. Steady state queuing delays will be 0.4375 sec, the same as with the static allocation model.

A.3.2.3 Effect of Monitoring Period. The theoretical model assumes that the monitoring period has been reduced to zero. Thus the queue is always servicing packets at the same rate they arrive. However, this assumption does not hold in practice. The monitoring period allows time to determine a more accurate measure of the instantaneous utilization. If bandwidth needs to be adjusted to allow circuits to reclaim bandwidth that was originally allocated to them, however, the queue size will increase linearly until the circuit's bandwidth is restored to its requested peak rate. Therefore, as Figure A.16 shows, observed queuing delays were much higher than that determined in the previous section.

A.3.3 5 Circuits.

A.3.3.1 Workload and Utilization. The circuits were configured with the same parameter values as the five-circuit configuration of the static system (see Table A.3). Additionally, the same assumptions were used to validate the model against the theoretical model as were given in Section A.3.2.1. The resulting offered load and utilization are shown in Figures A.17 and A.18. At t = 0, the instantaneous utilization is 0%, as expected. At t = 1200, the instantaneous utilization is initially 20% because Circuit 0 is allocated one-fifth of the bandwidth. Immediately, Circuit 0 is allocated all but 8192 bps of each of the remaining circuits' bandwidth, up to twice its originally assigned bandwidth. This results in a new data rate of 32768 bps for Circuit 0. Utilization at this point becomes 40% since Circuit 0 takes advantage of the increased bandwidth and Circuits 1-4 are still idle. At t = 1800, Circuits 1-4 become active and instantaneous utilization increases to 100%. Immediately, Circuit 0 reduces its bandwidth and data rate from 32768 bps to 16384 bps while

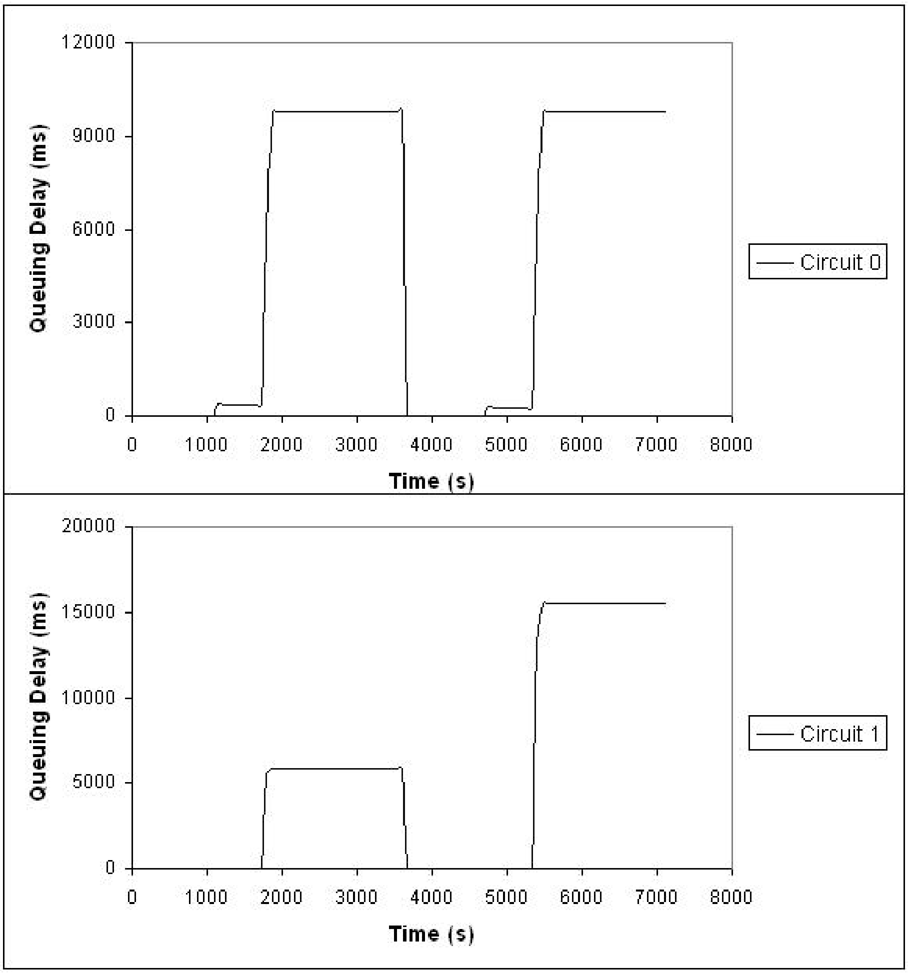

Figure A.16. Two-Circuit Configuration Queuing Delay — DBA Method the remaining circuits reset their bandwidths to 16384 bps. Instantaneous utilization remains at 100% until the off period at t = 3600.

A.3.3.2 Queuing Delay. Using the workload described above with dynamic allocation, there are four possible states the system could be in, which could affect queuing delay. Three of these will be discussed in turn. The fourth occurs when neither circuit is transmitting, resulting in a zero queuing delay.

Circuit 0 On, Circuits 1-4 Off, Before Reallocation: When Circuit 0 initially becomes active, the bandwidth allocations are at the originally assigned levels. Therefore, the expected queuing delay will be the same as that shown under the static model: 0.5 sec. Note that the remaining circuits' queuing delays should be zero since they are inactive at that time. It should also be noted that, under the assumption of instantaneous reallocation, this delay level would not be seen.

Circuit 0 On, Circuits 1-4 Off, After Reallocation: Figure A.19 depicts the packet arrivals and time slot allocations for the first and subsequent TDM iterations in this configuration. It also depicts the packet servicing of the first TDM iteration. Once bandwidth is reallocated to 32768 bps for Circuit 0 and 8192 bps for Circuits 1 and 2, the time slot allocations will be as shown in the figure. If $\lambda = 8$ pps and $\mu = 20$ pps, then the expected service time is as shown in Equation A.8.

$$E(s) = \frac{1}{\mu} = 0.05 \text{ sec} \tag{A.8}$$

A.3.3.2.1 Packet Arrivals. Circuit 0's arrival rate is 8 pps; Circuits 1-4 are idle. Therefore, the aggregate arrival rate is 8 pps. Packets arrive synchronously and one will arrive every 0.125 sec. Each arriving packet will be queued up in Circuit 0's subqueue until it can be serviced. In the diagram above, packet arrivals are designated by the same convention as that given in Section A.3.2.2.1 (i.e. Pkt Ckt#-Pkt#).

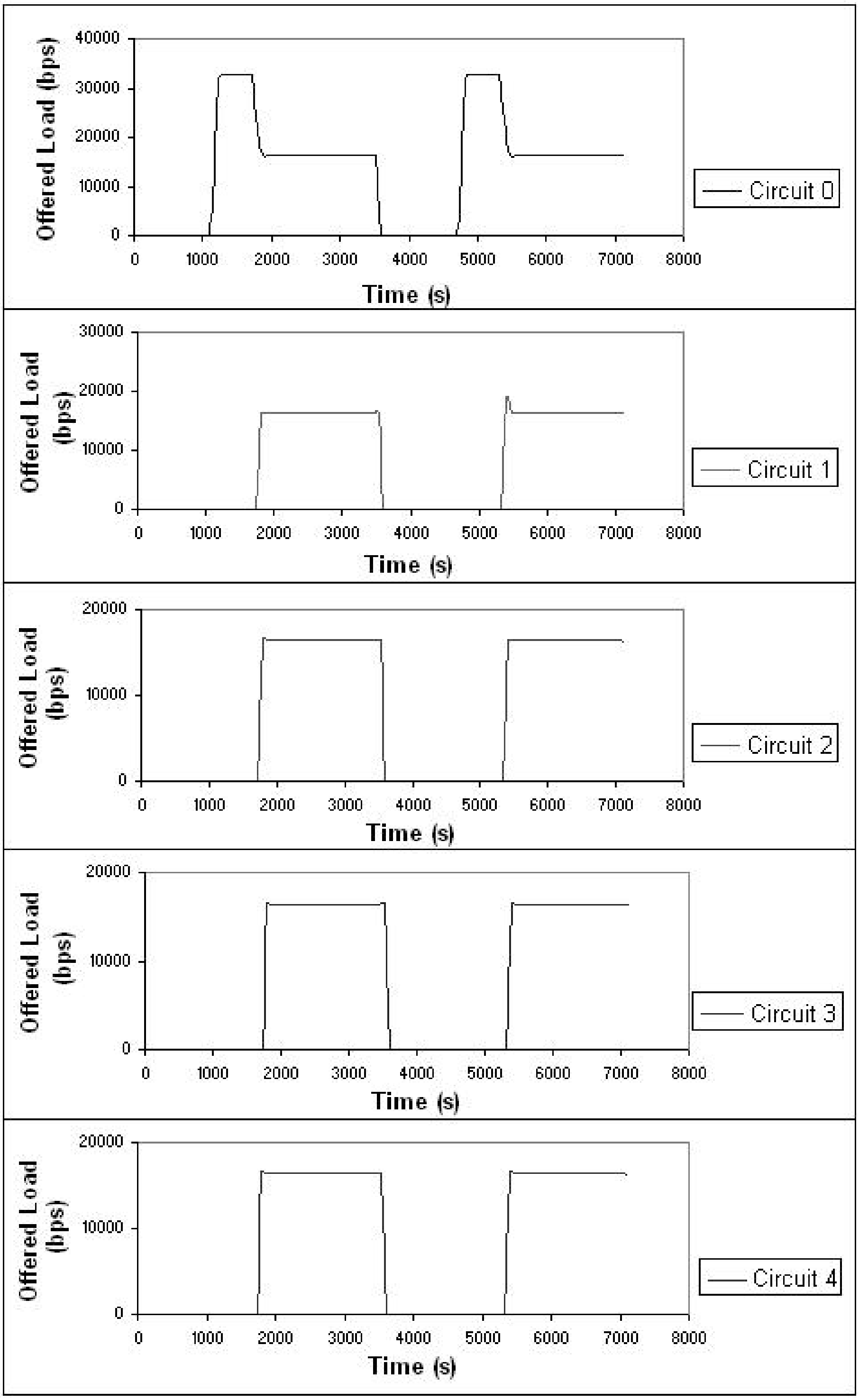

Figure A.17. Five-Circuit Configuration Workload — DBA Method

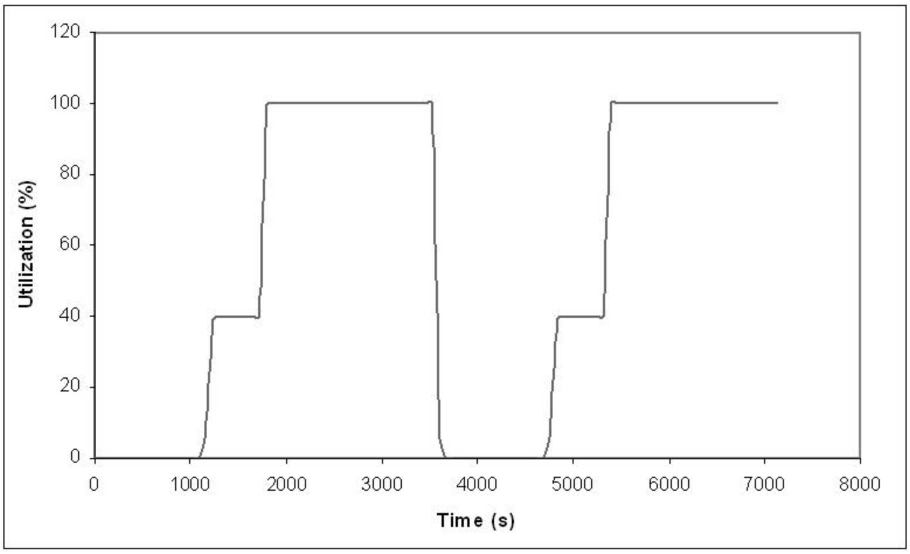

Figure A.18. Five-Circuit Configuration Utilization — DBA Method

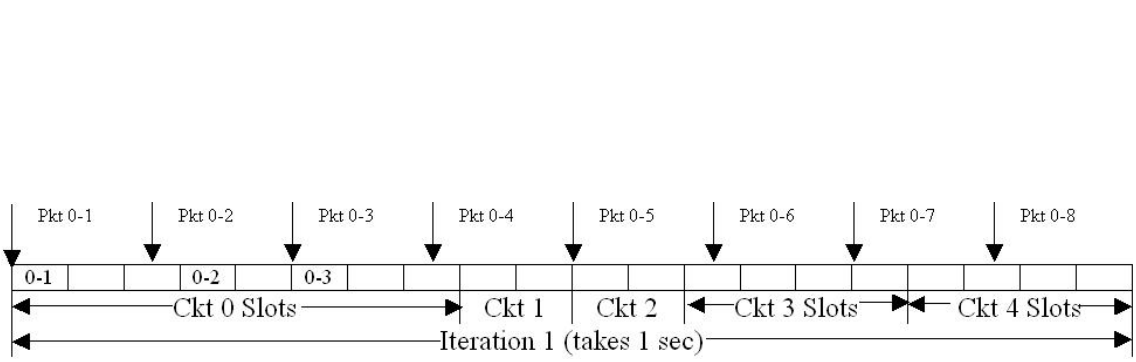

Figure A.19. Five-Circuit Configuration Time Slot Allocation — DBA Method

A.3.3.2.2 Packet Servicing. Circuit 0's data rate under this configuration is 32768 bps or 8 pps. Therefore, it will be allotted eight time slots per second. These are allocated contiguously as shown in the diagram above. At t = 0, Pkt 0-1, which has just arrived, can be serviced immediately. This results in a waiting time of zero seconds and a total time in system of 0 sec + 0.05 sec = 0.05 sec. The time slots at times 0.05 and 0.10 go empty because there are no new packets queued up. However, Pkt 0-2 is serviced at t = 0.15. Its waiting time is 0.025 sec yielding a total time in system of 0.075 sec. The time slot at t = 0.20 goes empty since no new packets have arrived. At t = 0.25, Pkt 0-3, which has just arrived can be serviced immediately. Therefore, its total time in system is 0.05 sec. No more packets are serviced during this iteration because Circuit 0 has no new packets arrive prior to the passing of its time slots and Circuits 1-4 are idle.

At this point, Pkts 0-4 through 0-8 are queued up and are serviced in the first four time slots of the next iteration. The waiting times experienced by these packets are 0.625 sec, 0.550 sec, 0.475 sec, 0.400 sec, and 0.325 sec, respectively. This results in total times in system of 0.675 sec, 0.600 sec, 0.525 sec, 0.450 sec, and 0.375 sec for the five packets. Pkts 0-1 through 0-3 will be serviced in Circuit 0's last three time slots. The average total time in system for each packet will be 0.4125 sec.

Circuit 0 On, Circuits 1-4 On, After Reallocation: At t = 1800, the remaining circuits become active and begin transmitting at 16384 bps. Circuits 1 and 2 will only be able to transmit half of the arriving packets during each second, however, since their slot allocations have been cut in half. Therefore, queuing delay will increase without bound as long as its assigned bandwidth is only 8192 bps. Since the theoretical model assumes instantaneous reallocation, though, this problem will never occur.

A.3.3.3 Effect of Monitoring Period. The theoretical model assumes that the monitoring period has been reduced to zero. Thus the queue is always

Table A.4. Seed Independence Results — Static Allocation Method, 1 Circuit

	Utilization (%)	Queuing Delay (ms)
Seed 128	53.27	130.12
Seed 129	47.17	124.58
Seed 130	50.53	119.46
Mean	**50.32**	**124.72**
Variance	**9.35**	**28.47**

Table A.5. Seed Independence Results — Static Allocation Method, 2 Circuits

	Utilization (%)	Queuing Delay (ms)	
		Circuit 0	Circuit 1
Seed 128	51.63	272.21	289.36
Seed 129	49.47	267.83	311.34
Seed 130	54.97	272.05	319.06
Mean	**52.02**	**270.69**	**306.59**
Variance	**7.67**	**6.18**	**237.56**

servicing packets at the same rate they arrive. However, this assumption does not hold in practice. The monitoring period allows time to determine a more accurate measure of the instantaneous utilization. If bandwidth needs to be adjusted to allow circuits to reclaim bandwidth that was originally allocated to them, the queue size will increase linearly until the circuit's bandwidth is restored to its requested peak rate. Therefore, as Figure A.20 shows, observed queuing delays were much higher than that determined in the previous section.

A.4 Seed Independence

Up to this point, the models have been tested with constant-valued ON and OFF periods. Since the exponential distribution would be used in the actual tests, however, the static and dynamic models were also subjected to the same tests as before. This time, however, the mean ON and OFF periods were exponentially distributed and three different random seeds were used. The objective was to determine whether the results obtained across varying random seeds were similar. Tables A.4-A.9 provide the utilization and queuing delay values obtained through simulation as well as the mean and variance of the data for both models.

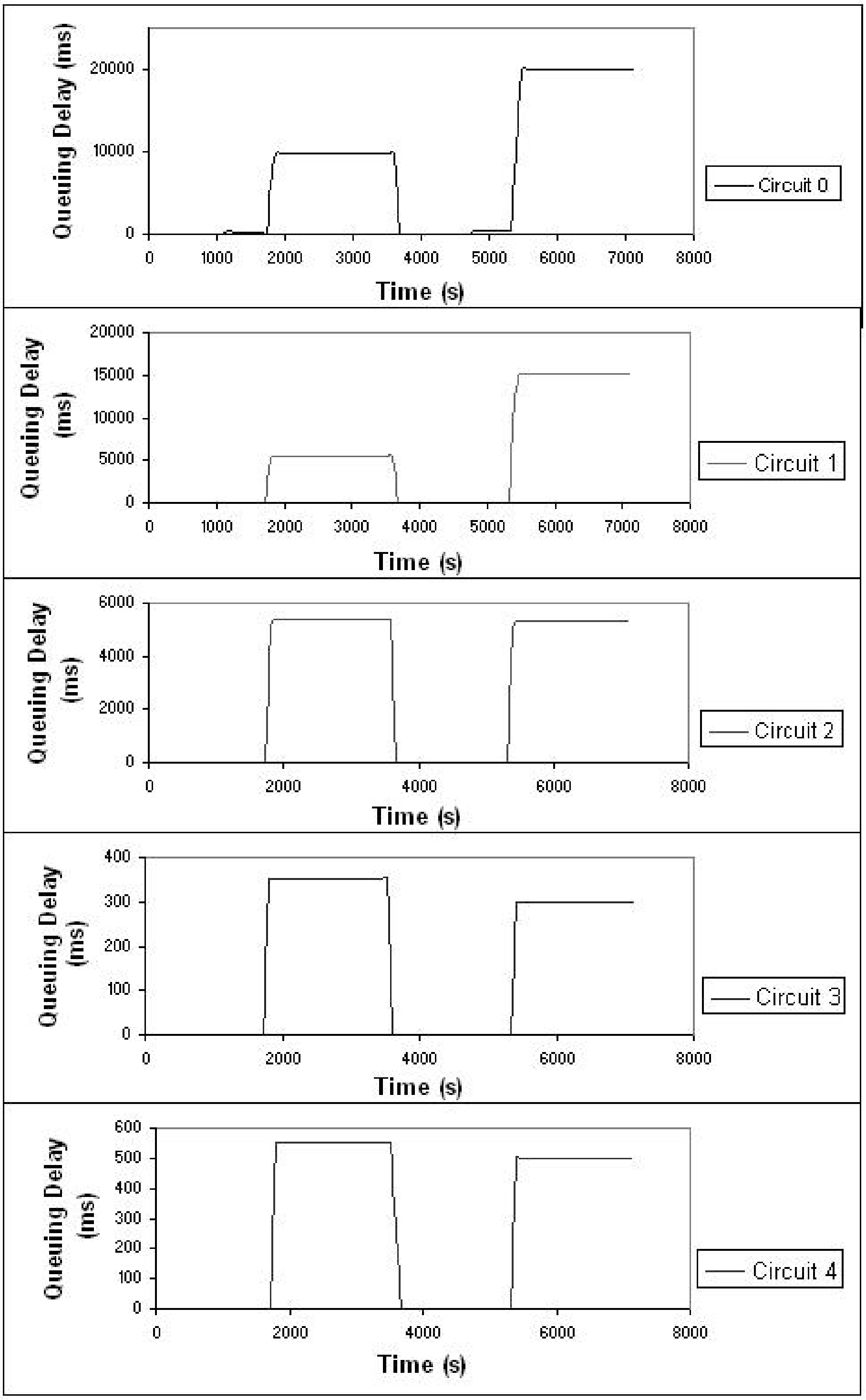

Figure A.20. Five-Circuit Configuration Queuing Delay — DBA Method

Table A.6. Seed Independence Results — Static Allocation Method, 5 Circuits

	Utilization (%)	Queuing Delay (ms)				
		Circuit 0	Circuit 1	Circuit 2	Circuit 3	Circuit 4
Seed 128	52.89	402.66	445.17	419.13	438.39	437.81
Seed 129	46.51	399.78	437.35	422.46	421.73	417.61
Seed 130	48.27	401.04	427.19	425.35	416.55	424.30
Mean	**49.22**	**401.16**	**436.57**	**422.31**	**425.56**	**426.58**
Variance	**10.86**	**2.09**	**81.26**	**9.69**	**130.21**	**105.86**

Table A.7. Seed Independence Results — DBA Method, 1 Circuit

	Utilization (%)	Queuing Delay (ms)
Seed 128	53.27	130.12
Seed 129	47.17	124.58
Seed 130	50.53	119.46
Mean	**50.32**	**124.72**
Variance	**9.35**	**28.47**

Table A.8. Seed Independence Results — DBA Method, 2 Circuits

	Utilization (%)	Queuing Delay (s)	
		Circuit 0	Circuit 1
Seed 128	65.81	0.518	108.075
Seed 129	65.65	0.568	105.660
Seed 130	66.65	0.579	123.418
Mean	**66.04**	**0.555**	**112.384**
Variance	**0.29**	**0.001**	**92.765**

Table A.9. Seed Independence Results — DBA Method, 5 Circuits

	Utilization (%)	Queuing Delay (s)				
		Circuit 0	Circuit 1	Circuit 2	Circuit 3	Circuit 4
Seed 128	60.82	19.44	130.69	112.32	132.85	95.63
Seed 129	57.51	23.69	105.69	109.67	93.11	101.68
Seed 130	62.78	24.81	123.04	141.32	120.66	110.65
Mean	**60.37**	**22.65**	**119.81**	**121.10**	**115.54**	**102.66**
Variance	**7.09**	**8.02**	**164.03**	**308.36**	**414.49**	**57.13**

Appendix B. Statistical Data

Table B.1. Utilization Data — Static Assignment TDM

	System Underload	Data Overload	Voice Overload	Voice & Data Overload
Seed 128	13.21	29.57	20.29	36.78
Seed 129	13.23	29.46	20.35	36.57
Seed 130	13.34	29.58	20.41	36.51
Seed 131	13.32	29.59	20.44	36.51
Seed 132	13.16	29.47	20.35	36.57
Column Mean	**13.25**	**29.53**	**20.37**	**36.59**

Table B.2. Voice Circuit Queuing Delay Data — Static Assignment TDM

	System Underload	Data Overload	Voice Overload	Voice & Data Overload
Seed 128	260.23	260.45	309.01	309.23
Seed 129	260.33	260.05	309.39	309.27
Seed 130	260.41	260.62	308.91	309.46
Seed 131	260.07	260.06	309.26	309.31
Seed 132	260.46	260.46	309.15	309.48
Column Mean	**260.30**	**260.33**	**309.15**	**309.35**

Table B.3. Video Circuit Queuing Delay Data — Static Assignment TDM

	System Underload	Data Overload	Voice Overload	Voice & Data Overload
Seed 128	336.13	334.66	336.48	332.79
Seed 129	335.23	336.04	335.02	335.22
Seed 130	335.01	335.79	334.57	336.26
Seed 131	335.98	334.48	336.45	335.78
Seed 132	332.59	334.88	336.00	336.14
Column Mean	**334.99**	**335.17**	**335.70**	**335.24**

Table B.4. NIPRNET Circuit Queuing Delay Data — Static Assignment TDM

	System Underload	Data Overload	Voice Overload	Voice & Data Overload
Seed 128	374.06	399.09	373.76	399.27
Seed 129	374.46	399.28	373.70	399.09
Seed 130	373.47	399.19	373.79	399.00
Seed 131	373.44	399.16	373.39	399.02
Seed 132	373.03	399.09	373.78	399.20
Column Mean	**373.69**	**399.16**	**373.68**	**399.12**

Table B.5. SIPRNET Circuit Queuing Delay Data — Static Assignment TDM

	All Circuits Underload	Data Overload	Voice Overload	Voice & Data Overload
Seed 128	373.60	398.95	373.62	399.07
Seed 129	373.38	399.41	373.65	399.32
Seed 130	373.99	399.08	373.81	399.01
Seed 131	373.69	399.42	373.75	399.38
Seed 132	373.48	399.15	373.73	399.12
Column Mean	**373.63**	**399.20**	**373.71**	**399.18**

Table B.6. Utilization Data — DBA-1

	Allocation Granularity: 8 kbps			**Allocation Granularity: 32 kbps**			**Allocation Granularity: 64 kbps**		
Offered Load	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**
System Underload	19.50	19.97	19.49	19.50	19.50	19.49	19.50	19.50	19.49
	21.12	20.88	21.12	21.12	21.12	21.12	21.12	21.12	21.12
	17.96	17.92	17.94	17.96	17.96	17.96	17.96	17.96	17.96
	18.59	18.96	18.59	18.59	18.60	18.59	18.60	18.60	18.60
	20.37	19.30	20.34	20.37	20.37	20.37	20.37	20.37	20.37
Data Overload	49.30	48.65	46.83	50.11	47.91	47.18	47.77	46.15	45.29
	48.93	49.12	47.03	50.54	48.58	47.33	48.66	45.93	46.63
	50.20	48.43	48.85	50.18	48.29	48.85	47.17	46.45	45.91
	49.16	48.87	49.06	48.43	48.65	49.06	47.31	45.87	45.92
	50.41	48.48	47.44	49.66	49.54	47.44	46.63	47.75	44.70
Voice Overload	29.99	28.32	28.32	29.98	28.91	27.31	27.80	27.48	27.50
	29.43	28.98	28.03	30.03	28.52	27.99	28.52	26.77	27.80
	29.35	27.85	28.24	30.14	27.23	27.35	27.79	27.82	27.56
	29.64	29.09	28.24	29.38	28.81	28.20	28.30	27.88	27.14
	29.33	28.79	27.80	31.51	29.43	27.84	28.41	28.54	26.74
Voice & Data Overload	47.32	47.06	48.61	46.88	46.41	48.61	46.28	46.03	46.39
	47.64	46.37	47.39	47.90	46.53	47.85	46.55	46.16	46.99
	47.74	46.57	47.58	47.06	46.72	47.85	45.07	44.69	47.15
	46.67	46.23	48.32	48.03	47.55	48.32	47.38	46.86	46.78
	47.31	46.45	47.44	47.91	47.12	47.44	47.15	46.39	46.41

Table B.7. Utilization Means — DBA-1

	Allocation Granularity: 8 kbps			**Allocation Granularity: 32 kbps**			**Allocation Granularity: 64 kbps**					
Offered Load	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Row Sum**	**Row Mean**	**Row Effect**
System Underload	19.51	19.40	19.49	19.51	19.51	19.51	19.51	19.51	19.51	175.47	19.50	-16.25
Data Overload	49.60	48.71	47.84	49.78	48.59	47.97	47.51	46.43	45.69	432.13	48.01	12.26
Voice Overload	29.55	28.60	28.12	30.21	28.58	27.74	28.17	27.70	27.35	256.02	28.45	-7.30
Voice & Data Overload	47.34	46.54	47.87	47.55	46.87	48.01	46.49	46.03	46.75	423.43	47.05	11.30
Column Sum	146.00	143.25	143.33	147.05	143.55	143.23	141.67	139.67	139.30	1287.05		
Column Mean	36.50	35.81	35.83	36.76	35.89	35.81	35.42	34.92	34.82		**35.75**	
Column Effect	0.75	0.06	0.08	1.01	0.14	0.06	-0.33	-0.83	-0.93			

Table B.8. Utilization Standard Deviations — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**
System Underload	1.283	1.109	1.284	1.284	1.282	1.282	1.282	1.282	1.282
Data Overload	0.664	0.284	1.042	0.819	0.603	0.906	0.761	0.771	0.730
Voice Overload	0.275	0.515	0.211	0.788	0.824	0.394	0.344	0.647	0.412
Voice & Data Overload	0.419	0.319	0.559	0.539	0.465	0.456	0.906	0.811	0.341

Table B.9. Utilization Difference Data — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**
System Underload	6.28	6.76	6.28	6.28	6.28	6.28	6.28	6.28	6.28
	7.89	7.65	7.89	7.89	7.89	7.89	7.89	7.89	7.89
	4.62	4.57	4.60	4.62	4.62	4.62	4.62	4.62	4.62
	5.28	5.65	5.28	5.27	5.28	5.28	5.28	5.28	5.28
	7.21	6.13	7.18	7.21	7.21	7.20	7.21	7.21	7.21
Data Overload	19.73	19.08	17.26	20.54	18.34	17.61	18.20	16.58	15.72
	19.47	19.66	17.57	21.08	19.13	17.87	19.20	16.48	17.18
	20.63	18.86	19.27	20.60	18.72	19.27	17.59	16.87	16.34
	19.58	19.28	19.48	18.84	19.07	19.48	17.73	16.29	16.34
	20.94	19.01	17.97	20.18	20.06	17.97	17.16	18.28	15.23
Voice Overload	9.70	8.03	8.03	9.69	8.62	7.02	7.51	7.19	7.21
	9.09	8.63	7.68	9.69	8.18	7.65	8.17	6.42	7.45
	8.94	7.44	7.83	9.73	6.82	6.94	7.38	7.41	7.15
	9.20	8.65	7.80	8.94	8.37	7.76	7.86	7.45	6.70
	8.98	8.43	7.45	11.16	9.08	7.48	8.06	8.19	6.39
Voice & Data Overload	10.54	10.28	11.83	10.09	9.63	11.83	9.50	9.25	9.61
	11.07	9.81	10.82	11.33	9.96	11.28	9.98	9.59	10.42
	11.24	10.06	11.08	10.56	10.21	11.34	8.56	8.18	10.65
	10.16	9.72	11.80	11.51	11.04	11.80	10.87	10.35	10.27
	10.74	9.88	10.87	11.34	10.55	10.87	10.59	9.82	9.84

Table B.10. Utilization Difference Means — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**
System Underload	6.26	6.15	6.24	6.26	6.26	6.26	6.26	6.26	6.26
Data Overload	20.07	19.18	18.31	20.25	19.06	18.44	17.98	16.90	16.16
Voice Overload	9.18	8.24	7.76	9.84	8.21	7.37	7.80	7.33	6.98
Voice & Data Overload	10.75	9.95	11.28	10.97	10.28	11.43	9.90	9.44	10.16

Table B.11. Utilization Difference Standard Deviations — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**	**Monitoring Period (5)**	**Monitoring Period (10)**	**Monitoring Period (50)**
System Underload	1.343	1.156	1.343	1.344	1.342	1.342	1.342	1.342	1.341
Data Overload	0.669	0.310	1.006	0.849	0.643	0.867	0.780	0.799	0.735
Voice Overload	0.306	0.512	0.213	0.809	0.850	0.371	0.342	0.634	0.427
Voice & Data Overload	0.428	0.223	0.499	0.612	0.541	0.399	0.916	0.808	0.425

Table B.12. Utilization Difference 90% Confidence Intervals — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	4.98	5.05	4.96	4.98	4.98	4.98	4.98	4.98	4.98
	7.54	7.25	7.52	7.54	7.54	7.53	7.54	7.54	7.54
Data Overload	19.43	18.88	17.35	19.44	18.45	17.61	17.23	16.14	15.46
	20.71	19.47	19.27	21.06	19.68	19.27	18.72	17.66	16.86
Voice Overload	8.89	7.75	7.55	9.07	7.40	7.02	7.47	6.73	6.57
	9.47	8.73	7.96	10.61	9.02	7.73	8.12	7.93	7.39
Voice & Data Overload	10.34	9.73	10.80	10.38	9.76	11.05	9.03	8.67	9.75
	11.16	10.16	11.76	11.55	10.79	11.81	10.77	10.21	10.56

Table B.13. Utilization Main Effects — DBA-1

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-16.25	12.26	-7.30	11.30
Allocation Granularity	B	0.30	0.40	-0.70	N/A
Monitoring Period	C	0.48	-0.21	-0.26	N/A

Table B.14. Utilization Second Order Interaction Effects — DBA-1

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	-0.32	0.41	0.02	-0.10
32 kbps	-0.39	0.37	-0.01	0.03
64 kbps	0.71	-0.77	-0.01	0.07

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	-0.46	0.47	0.39	-0.40
10 s	0.19	0.11	0.06	-0.36
50 s	0.27	-0.58	-0.45	0.76

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	-0.02	0.13	-0.11
10 s	-0.02	-0.05	0.08
50 s	0.05	-0.08	0.03

Table B.15. Utilization Third Order Interaction Effects — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.05	-0.02	-0.03	-0.15	0.08	0.07	0.10	-0.05	-0.04
Data Overload	-0.04	0.12	-0.08	-0.08	-0.03	0.12	0.13	-0.09	-0.04
Voice Overload	-0.05	0.02	0.03	0.37	-0.06	-0.31	-0.32	0.04	0.29
Voice & Data Overload	0.04	-0.12	0.08	-0.14	0.01	0.12	0.10	0.10	-0.20

Table B.16. Utilization Analysis of Variance — DBA-1

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
257095.27	230068.50	26800.94	44.25	20.43	25.13	31.67	1.00	3.32	27026.78	100.03

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
99.16%	0.16%	0.08%	0.09%	0.12%	0.00%	0.01%	0.37%

Table B.17. Voice Circuit Queuing Delay Data — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
	317.18	274.76	266.44	260.27	261.33	257.75	255.74	252.82	260.21
	317.10	283.82	388.41	265.20	262.53	300.68	257.91	256.63	274.38
System Underload	296.73	275.36	413.38	251.22	252.40	307.61	251.66	250.54	259.26
	306.94	275.10	282.69	254.81	254.93	264.84	252.98	250.78	256.88
	325.75	277.75	268.44	260.95	263.14	267.61	255.76	254.49	262.16
	362.54	394.78	696.76	371.04	392.61	660.13	330.52	337.97	448.43
	358.97	407.14	668.17	379.57	397.43	732.94	331.72	338.12	429.52
Data Overload	379.37	394.82	731.73	381.20	393.08	731.73	330.60	341.90	415.13
	365.56	401.67	767.90	362.03	391.64	767.90	327.62	337.14	442.91
	379.13	401.31	687.26	367.11	413.01	687.26	329.94	343.27	460.49
	224.47	226.17	346.75	228.33	231.64	264.65	240.72	252.80	329.21
	221.47	229.06	270.62	228.18	231.16	328.39	243.98	250.76	331.51
Voice Overload	221.20	227.04	284.00	227.91	224.52	309.26	242.51	254.34	320.76
	224.07	226.54	261.73	226.97	231.77	311.31	243.51	249.31	351.51
	222.51	229.84	292.26	236.17	230.67	322.38	245.31	260.73	307.41
	312.66	353.66	621.34	315.24	351.98	621.34	316.95	364.86	576.93
	316.82	345.88	568.43	315.76	346.20	578.36	323.90	358.89	604.23
Voice & Data Overload	314.10	354.85	577.60	309.77	356.35	618.88	313.34	346.09	566.75
	307.94	343.96	591.65	318.88	359.09	591.65	324.46	362.19	552.12
	315.31	353.16	553.96	321.06	360.85	553.96	326.82	366.61	548.75

Table B.18. Voice Circuit Queuing Delay Means — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean	Row Effect
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)			
System Underload	312.74	277.36	323.87	258.49	258.87	279.70	254.81	253.05	262.58	2481.47	275.72	-75.66
Data Overload	369.11	399.94	710.36	372.19	397.55	715.99	330.08	339.68	439.30	4074.21	452.69	101.32
Voice Overload	222.75	227.73	291.07	229.51	229.95	307.20	243.20	253.59	328.08	2333.08	259.23	-92.14
Voice & Data Overload	313.37	350.30	582.59	316.14	354.89	592.84	321.09	359.73	569.76	3760.72	417.86	66.48
Column Sum	1217.97	1255.33	1907.90	1176.33	1241.27	1895.72	1149.19	1206.05	1599.71	12649.47		
Column Mean	304.49	313.83	476.98	294.08	310.32	473.93	287.30	301.51	399.93		**351.37**	
Column Effect	268.74	278.08	441.22	258.33	274.57	438.18	251.55	265.76	364.18			

Table B.19. Voice Circuit Queuing Delay Standard Deviations — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	11.159	3.801	71.140	5.490	4.873	22.738	2.482	2.569	6.866
Data Overload	9.542	5.234	39.580	8.155	8.921	42.356	1.518	2.721	17.502
Voice Overload	1.485	1.626	33.283	3.759	3.069	25.054	1.715	4.431	16.145
Voice & Data Overload	3.400	4.997	25.636	4.280	5.901	28.341	5.685	8.164	22.367

Table B.20. Voice Circuit Queuing Delay Difference Data — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	56.95	14.52	6.20	0.04	1.09	-2.48	-4.49	-7.41	-0.02
	56.77	23.49	128.08	4.87	2.20	40.35	-2.42	-3.70	14.05
	36.32	14.95	152.97	-9.19	-8.01	47.20	-8.75	-9.87	-1.15
	46.87	15.03	22.62	-5.26	-5.14	4.77	-7.09	-9.30	-3.19
	65.29	17.29	7.98	0.49	2.68	7.14	-4.71	-5.97	1.70
Data Overload	102.09	134.33	436.31	110.58	132.15	399.67	70.06	77.52	187.98
	98.91	147.09	408.11	119.52	137.38	472.89	71.66	78.07	169.47
	118.75	134.19	471.11	120.57	132.46	471.11	69.98	81.28	154.51
	105.50	141.61	507.84	101.97	131.58	507.84	67.57	77.09	182.85
	118.66	140.85	426.79	106.64	152.54	426.79	69.48	82.81	200.03
Voice Overload	-84.54	-82.84	37.74	-80.68	-77.37	-44.36	-68.29	-56.21	20.20
	-87.92	-80.33	-38.77	-81.21	-78.24	18.99	-65.41	-58.63	22.11
	-87.71	-81.87	-24.91	-81.00	-84.39	0.35	-66.40	-54.57	11.85
	-85.19	-82.73	-47.54	-82.29	-77.49	2.05	-65.76	-59.95	42.24
	-86.64	-79.31	-16.89	-72.98	-78.48	13.23	-63.85	-48.42	-1.74
Voice & Data Overload	3.43	44.43	312.11	6.01	42.75	312.11	7.72	55.63	267.71
	7.55	36.61	259.15	6.49	36.93	269.09	14.63	49.62	294.96
	4.64	45.39	268.14	0.31	46.89	309.42	3.88	36.63	257.29
	-1.38	34.65	282.34	9.56	49.78	282.34	15.14	52.88	242.81
	5.83	43.68	244.48	11.59	51.37	244.48	17.34	57.14	239.27

Table B.21. Voice Circuit Queuing Delay Difference Means — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	52.44	17.06	63.57	-1.81	-1.43	19.40	-5.49	-7.25	2.28
Data Overload	108.78	139.61	450.03	111.86	137.22	455.66	69.75	79.35	178.97
Voice Overload	-86.40	-81.42	-18.07	-79.63	-79.20	-1.95	-65.94	-55.56	18.93
Voice & Data Overload	4.02	40.95	273.24	6.79	45.54	283.49	11.74	50.38	260.41

Table B.22. Voice Circuit Queuing Delay Difference Standard Deviations — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	11.126	3.757	71.085	5.469	4.834	22.666	2.462	2.515	6.819
Data Overload	9.352	5.447	39.598	8.080	8.874	42.504	1.471	2.540	17.524
Voice Overload	1.502	1.547	33.392	3.767	2.944	24.944	1.615	4.504	16.067
Voice & Data Overload	3.377	4.947	25.716	4.284	5.825	28.380	5.684	8.204	22.434

Table B.23. Voice Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	41.83 63.05	13.47 20.64	-4.21 131.35	-7.02 3.40	-6.04 3.17	-2.21 41.01	-7.84 -3.14	-9.65 -4.85	-4.23 8.78
Data Overload	99.87 117.70	134.42 144.81	412.28 487.79	104.15 119.56	128.76 145.68	415.13 496.19	68.35 71.15	76.93 81.77	162.26 195.68
Voice Overload	-87.83 -84.97	-82.89 -79.94	-49.91 13.76	-83.23 -76.04	-82.00 -76.39	-25.73 21.83	-67.48 -64.40	-59.85 -51.26	3.61 34.25
Voice & Data Overload	0.80 7.24	36.23 45.67	248.72 297.76	2.71 10.88	39.99 51.10	256.43 310.55	6.32 17.16	42.56 58.20	239.02 281.80

Table B.24. Voice Circuit Queuing Delay Main Effects — DBA-1

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-75.66	101.32	-92.14	66.48
Allocation Granularity	B	13.73	8.07	-21.80	N/A
Monitoring Period	C	-56.08	-42.82	98.90	N/A

Table B.25. Voice Circuit Queuing Delay Second Order Interaction Effects — DBA-1

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	15.21	26.72	-25.77	-16.16
32 kbps	-18.10	34.48	-11.75	-4.64
64 kbps	2.89	-61.21	37.52	20.80

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	55.71	-39.48	28.67	-44.91
10 s	30.19	-30.81	20.68	-20.06
50 s	-85.91	70.29	-49.35	64.97

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	-4.52	-9.28	13.80
10 s	-8.45	-6.31	14.75
50 s	12.97	15.58	-28.56

Table B.26. Voice Circuit Queuing Delay Third Order Interaction Effects — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	12.98	-6.23	-6.75	2.45	12.11	-14.57	-15.43	-5.89	21.32
Data Overload	-23.94	-11.12	35.06	-18.22	-17.75	35.97	42.16	28.87	-71.03
Voice Overload	7.50	11.13	-18.63	10.65	2.85	-13.49	-18.14	-13.98	32.12
Voice & Data Overload	3.46	6.21	-9.67	5.12	2.79	-7.91	-8.58	-9.00	17.58

Table B.27. Voice Circuit Queuing Delay Analysis of Variance — DBA-1

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
25200708.88	22223489.50	1300459.90	43712.13	885653.15	137140.00	437538.86	37046.29	79796.19	2977219.37	55872.86

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
43.68%	1.47%	29.75%	4.61%	14.70%	1.24%	2.68%	1.88%

Table B.28. Video Circuit Queuing Delay Data — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	303.35	368.64	1995.46	266.16	342.03	1808.90	280.00	357.97	1655.04
	252.59	373.41	1676.96	279.69	271.13	837.97	278.25	305.32	585.17
	305.42	507.81	2558.22	306.18	306.70	778.61	273.23	421.92	280.49
	260.09	326.16	1668.98	255.40	345.55	1932.63	272.85	325.86	1010.54
	348.36	460.85	2257.51	300.79	368.93	1825.66	285.76	360.17	637.73
Data Overload	280.67	296.84	2404.90	289.55	589.11	3325.47	278.22	334.79	2033.98
	335.83	424.20	2718.66	307.85	418.29	1296.22	283.49	321.61	1038.00
	343.68	440.30	2579.79	390.00	631.47	2579.79	266.73	446.74	940.83
	310.09	499.34	2105.24	429.58	617.29	2105.24	298.90	607.72	1603.77
	450.82	704.80	1930.49	333.04	331.15	1930.49	261.40	294.11	1331.51
Voice Overload	786.72	1437.83	4258.26	816.70	1195.57	3953.97	786.72	888.30	3904.58
	745.02	1099.44	5733.91	1019.35	1417.43	6940.87	745.02	949.52	3416.93
	614.10	1606.58	5125.98	1274.74	2671.39	6189.54	614.10	1177.93	2651.19
	729.31	1749.26	5785.14	1158.11	2104.97	3687.30	729.31	1407.10	3509.14
	524.55	1622.87	6508.93	928.68	1230.65	4359.33	524.55	1568.52	2062.87
Voice & Data Overload	814.32	1259.66	4926.38	1420.17	1460.59	4926.38	620.41	1071.02	4893.39
	969.26	1347.47	4420.79	1079.90	1494.14	5422.27	814.05	1352.29	4145.35
	939.91	1345.05	4653.65	811.71	1822.71	4765.02	768.94	1536.73	4124.69
	892.39	1355.69	5047.73	993.28	1793.21	5047.73	1031.08	644.66	5689.69
	761.05	1981.72	5419.19	801.83	2549.83	5419.19	1087.34	952.77	4826.17

Table B.29. Video Circuit Queuing Delay Means — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean	Row Effect
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)			
System Underload	293.96	407.37	2031.42	281.64	326.87	1436.76	278.02	354.25	833.79	6244.08	693.79	-887.74
Data Overload	344.22	473.10	2347.82	350.00	517.46	2247.44	277.74	400.99	1389.62	8348.39	927.60	-653.93
Voice Overload	679.94	1503.20	5482.44	1039.52	1724.00	5026.20	679.94	1198.27	3108.94	20442.45	2271.38	689.85
Voice & Data Overload	875.39	1457.92	4893.55	1021.38	1824.10	5116.12	864.36	1111.50	4735.86	21900.17	2433.35	851.82
Column Sum	2193.50	3841.58	14755.23	2692.54	4392.43	13826.52	2100.06	3065.01	10068.21	56935.09		
Column Mean	548.38	960.40	3688.81	673.14	1098.11	3456.63	525.02	766.25	2517.05		**1581.53**	
Column Effect	512.62	924.64	3653.06	637.38	1062.36	3420.88	489.26	730.50	2481.30			

Table B.30. Video Circuit Queuing Delay Standard Deviations — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	38.851	74.495	383.058	21.799	38.279	576.048	5.329	44.238	527.277
Data Overload	64.493	149.085	326.955	58.422	134.764	757.972	14.742	129.362	444.266
Voice Overload	107.881	251.422	841.756	181.477	644.070	1449.686	107.881	291.148	740.248
Voice & Data Overload	86.699	295.409	381.511	252.692	438.365	295.605	192.783	347.697	645.173

Table B.31. Video Circuit Queuing Delay Difference Data — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
	-32.78	32.51	1659.33	-69.97	5.90	1472.77	-56.13	21.84	1318.91
	-82.64	38.18	1341.73	-55.54	-64.09	502.75	-56.98	-29.91	249.94
System Underload	-29.59	172.80	2223.20	-28.84	-28.31	443.60	-61.79	86.90	-54.53
	-75.89	-9.82	1333.00	-80.58	9.57	1596.65	-63.13	-10.12	674.56
	15.78	128.27	1924.92	-31.80	36.35	1493.08	-46.83	27.58	305.14
	-53.99	-37.82	2070.24	-45.12	254.45	2990.80	-56.45	0.12	1699.32
	-0.21	88.17	2382.62	-28.19	82.25	960.19	-52.55	-14.43	701.96
Data Overload	7.89	104.51	2244.00	54.21	295.68	2244.00	-69.06	110.95	605.04
	-24.38	164.86	1770.77	95.10	282.81	1770.77	-35.58	273.24	1269.30
	115.94	369.92	1595.61	-1.84	-3.73	1595.61	-73.48	-40.77	996.63
	450.23	1101.35	3921.78	480.22	859.08	3617.49	450.23	551.82	3568.10
	410.00	764.42	5398.89	684.33	1082.42	6605.85	410.00	614.51	3081.92
Voice Overload	279.53	1272.01	4791.41	940.17	2336.82	5854.97	279.53	843.36	2316.62
	392.86	1412.82	5448.69	821.66	1768.52	3350.85	392.86	1070.66	3172.69
	188.55	1286.87	6172.93	592.68	894.65	4023.33	188.55	1232.52	1726.87
	481.52	926.86	4593.59	1087.38	1127.79	4593.59	287.62	738.23	4560.59
	634.04	1012.25	4085.58	744.69	1158.93	5087.05	478.84	1017.08	3810.14
Voice & Data Overload	603.65	1008.79	4317.39	475.45	1486.45	4428.76	432.68	1200.47	3788.43
	556.62	1019.91	4711.96	657.51	1457.43	4711.96	695.30	308.89	5353.91
	424.91	1645.58	5083.05	465.69	2213.69	5083.05	751.20	616.63	4490.03

Table B.32. Video Circuit Queuing Delay Difference Means — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-41.02	72.39	1696.44	-53.34	-8.12	1101.77	-56.97	19.26	498.80
Data Overload	9.05	137.93	2012.65	14.83	182.29	1912.27	-57.43	65.82	1054.45
Voice Overload	344.24	1167.49	5146.74	703.81	1388.30	4690.50	344.24	862.57	2773.24
Voice & Data Overload	540.15	1122.68	4558.31	686.14	1488.86	4780.88	529.13	776.26	4400.62

Table B.33. Video Circuit Queuing Delay Difference Standard Deviations — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	39.912	75.372	383.722	22.846	38.818	576.127	6.418	44.531	526.562
Data Overload	64.431	149.186	326.400	58.560	134.889	758.294	14.960	129.593	444.852
Voice Overload	107.645	251.097	841.813	181.989	644.512	1450.490	107.645	290.962	739.940
Voice & Data Overload	86.367	294.744	381.355	254.081	437.493	295.326	191.760	347.604	645.330

Table B.34. Video Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-79.08	0.52	1330.57	-75.13	-45.13	552.46	-63.09	-23.20	-3.25
	-2.97	144.25	2062.30	-31.56	28.90	1651.08	-50.85	61.72	1000.86
Data Overload	-52.38	-4.32	1701.44	-41.00	53.68	1189.27	-71.69	-57.74	630.30
	70.48	280.17	2323.86	70.67	310.90	2635.28	-43.16	189.38	1478.60
Voice Overload	241.60	928.08	4344.11	530.29	773.78	3307.51	241.60	585.15	2067.74
	446.87	1406.90	5949.37	877.33	2002.82	6073.48	446.87	1139.99	3478.74
Voice & Data Overload	457.80	841.65	4194.71	443.89	1071.73	4499.30	346.29	444.83	3785.32
	622.49	1403.71	4921.92	928.40	1905.99	5062.46	711.96	1107.69	5015.91

Table B.35. Video Circuit Queuing Delay Main Effects — DBA-1

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-887.74	-653.93	689.85	851.82
Allocation Granularity	B	151.00	161.09	-312.09	N/A
Monitoring Period	C	-999.35	-639.95	1639.30	N/A

Table B.36. Video Circuit Queuing Delay Second Order Interaction Effects — DBA-1

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	66.14	-23.55	132.81	-175.40
32 kbps	-173.12	-50.39	164.10	59.42
64 kbps	106.99	73.94	-296.91	115.98

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	590.11	395.74	-472.23	-513.62
10 s	308.99	176.20	-156.28	-328.90
50 s	-899.10	-571.94	628.51	842.52

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	-184.80	-70.13	254.93
10 s	-132.19	-4.57	136.76
50 s	316.98	74.71	-391.69

Table B.37. Video Circuit Queuing Delay Third Order Interaction Effects — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-22.91	-40.40	63.32	79.27	-19.36	-59.91	-56.35	59.76	-3.41
Data Overload	77.58	13.99	-91.57	-14.55	-52.52	67.07	-63.03	38.53	24.49
Voice Overload	-218.87	-123.59	342.46	-15.34	-71.77	87.11	234.21	195.36	-429.57
Voice & Data Overload	164.21	150.00	-314.21	-49.38	143.65	-94.28	-114.83	-293.65	408.48

Table B.38. Video Circuit Queuing Delay Analysis of Variance — DBA-1

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
909612390.75	450222916.79	108774526.21	8769079.04	245732691.85	3522311.09	52366953.18	7994643.90	4843495.30	459389473.96	27385773.38

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
23.68%	1.91%	53.49%	0.77%	11.40%	1.74%	1.05%	5.96%

Table B.39. NIPRNET Circuit Queuing Delay Data — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	283.22	306.99	362.40	286.98	295.73	305.94	283.29	287.98	290.00
	289.06	317.71	425.85	288.12	296.20	308.37	282.48	287.65	288.84
	279.08	289.10	320.49	285.63	288.03	291.38	282.33	286.84	288.00
	286.87	299.44	361.53	285.81	290.87	297.24	283.14	287.18	288.74
	289.17	303.20	382.42	288.04	296.07	309.47	282.85	287.13	289.24
Data Overload	270.12	271.58	272.67	269.46	271.47	271.52	276.67	278.64	280.08
	269.34	272.85	272.43	269.00	273.57	270.79	277.02	277.79	282.49
	270.13	271.04	273.48	269.09	270.04	273.48	276.31	278.14	287.30
	268.65	271.03	276.49	266.82	271.50	276.49	275.72	278.51	280.97
	269.99	271.18	271.70	269.29	271.79	271.70	275.92	280.55	279.87
Voice Overload	413.90	427.05	508.50	382.68	387.14	412.66	376.05	380.73	386.05
	410.94	417.54	489.84	385.53	383.18	385.28	375.84	377.29	383.40
	407.26	410.71	547.09	383.50	380.57	406.81	375.42	378.69	389.56
	416.22	426.14	497.11	381.81	386.44	386.64	375.69	377.61	390.88
	418.85	423.30	500.66	388.19	393.19	403.77	376.88	376.06	385.66
Voice & Data Overload	371.66	367.05	351.78	370.26	367.58	351.78	373.01	369.17	357.25
	371.21	367.50	352.91	370.87	366.85	353.23	372.53	370.30	359.73
	372.52	367.34	362.85	370.48	367.46	356.61	372.12	369.74	358.40
	371.05	367.30	352.73	371.05	367.97	352.73	374.70	369.38	360.54
	371.14	367.10	354.50	370.78	367.13	354.50	373.39	369.57	359.03

Table B.40. NIPRNET Circuit Queuing Delay Means — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean	Row Effect
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)			
System Underload	285.48	303.29	370.54	286.92	293.38	302.48	282.82	287.36	288.96	2701.22	300.14	-36.17
Data Overload	269.65	271.54	273.35	268.73	271.68	272.80	276.33	278.73	282.14	2464.94	273.88	-62.43
Voice Overload	413.43	420.95	508.64	384.34	386.11	399.03	375.97	378.08	387.11	3653.66	405.96	69.65
Voice & Data Overload	371.52	367.26	354.95	370.69	367.40	353.77	373.15	369.63	358.99	3287.35	365.26	28.95
Column Sum	1340.08	1363.03	1507.49	1310.68	1318.56	1328.08	1308.27	1313.79	1317.20	12107.17		
Column Mean	335.02	340.76	376.87	327.67	329.64	332.02	327.07	328.45	329.30		**336.31**	
Column Effect	299.27	305.01	341.12	291.92	293.89	296.27	291.32	292.70	293.55			

Table B.41. NIPRNET Circuit Queuing Delay Standard Deviations — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	4.313	10.464	38.252	1.185	3.732	7.845	0.410	0.452	0.733
Data Overload	0.643	0.766	1.863	1.084	1.262	2.287	0.533	1.074	3.066
Voice Overload	4.519	6.821	22.518	2.555	4.757	12.362	0.555	1.758	3.053
Voice & Data Overload	0.610	0.183	4.521	0.316	0.428	1.868	0.989	0.431	1.257

Table B.42. NIPRNET Circuit Queuing Delay Difference Data — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-90.84	-67.07	-11.67	-87.09	-78.33	-68.12	-90.77	-86.09	-84.07
	-85.40	-56.75	51.39	-86.33	-78.25	-66.09	-91.97	-86.81	-85.62
	-94.39	-84.37	-52.97	-87.84	-85.44	-82.08	-91.13	-86.63	-85.47
	-86.58	-74.01	-11.91	-87.64	-82.58	-76.20	-90.31	-86.26	-84.70
	-83.85	-69.83	9.40	-84.98	-76.96	-63.55	-90.17	-85.89	-83.78
Data Overload	-128.97	-127.51	-126.42	-129.63	-127.61	-127.57	-122.41	-120.45	-119.01
	-129.94	-126.43	-126.85	-130.27	-125.70	-128.48	-122.25	-121.49	-116.79
	-129.06	-128.14	-125.71	-130.10	-129.15	-125.71	-122.88	-121.05	-111.88
	-130.50	-128.13	-122.67	-132.34	-127.66	-122.67	-123.44	-120.65	-118.19
	-129.10	-127.91	-127.38	-129.79	-127.29	-127.38	-123.16	-118.53	-119.22
Voice Overload	40.14	53.29	134.75	8.93	13.38	38.90	2.29	6.98	12.29
	37.24	43.84	116.14	11.82	9.48	11.57	2.14	3.59	9.69
	33.46	36.92	173.29	9.71	6.78	33.01	1.63	4.90	15.77
	42.83	52.75	123.72	8.42	13.06	13.25	2.30	4.22	17.49
	45.07	49.52	126.88	14.41	19.41	29.98	3.10	2.27	11.88
Voice & Data Overload	-27.61	-32.22	-47.49	-29.01	-31.69	-47.49	-26.26	-30.10	-42.02
	-27.88	-31.60	-46.18	-28.22	-32.24	-45.87	-26.56	-28.79	-39.37
	-26.47	-31.65	-36.15	-28.52	-31.54	-42.38	-26.87	-29.26	-40.60
	-27.98	-31.72	-46.30	-27.97	-31.05	-46.30	-24.33	-29.65	-38.48
	-28.06	-32.10	-44.70	-28.42	-32.07	-44.70	-25.82	-29.64	-40.18

Table B.43. NIPRNET Circuit Queuing Delay Difference Means — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-88.21	-70.41	-3.15	-86.78	-80.31	-71.21	-90.87	-86.34	-84.73
Data Overload	-129.51	-127.62	-125.81	-130.43	-127.48	-126.36	-122.83	-120.43	-117.02
Voice Overload	39.75	47.26	134.96	10.66	12.42	25.35	2.29	4.39	13.43
Voice & Data Overload	-27.60	-31.86	-44.16	-28.43	-31.72	-45.35	-25.97	-29.49	-40.13

Table B.44. NIPRNET Circuit Queuing Delay Difference Standard Deviations — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	4.319	10.074	37.960	1.159	3.564	7.707	0.725	0.377	0.819
Data Overload	0.678	0.715	1.857	1.098	1.228	2.294	0.497	1.134	3.025
Voice Overload	4.576	6.898	22.447	2.468	4.760	12.247	0.527	1.740	3.149
Voice & Data Overload	0.652	0.283	4.589	0.386	0.467	1.933	0.998	0.490	1.331

Table B.45. NIPRNET Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-92.33	-80.01	-39.35	-87.88	-83.71	-78.56	-91.56	-86.70	-85.51
	-84.09	-60.80	33.04	-85.67	-76.91	-63.86	-90.18	-85.98	-83.95
Data Overload	-130.16	-128.31	-127.58	-131.47	-128.65	-128.55	-123.30	-121.51	-119.90
	-128.87	-126.94	-124.04	-129.38	-126.31	-124.18	-122.36	-119.35	-114.13
Voice Overload	35.39	40.69	113.55	8.30	7.88	13.67	1.79	2.73	10.42
	44.11	53.84	156.36	13.01	16.96	37.02	2.79	6.05	16.43
Voice & Data Overload	-28.22	-32.13	-48.54	-28.80	-32.16	-47.19	-26.92	-29.95	-41.40
	-26.98	-31.59	-39.79	-28.06	-31.27	-43.50	-25.02	-29.02	-38.86

Table B.46. NIPRNET Circuit Queuing Delay Main Effects — DBA-1

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-36.17	-62.43	69.65	28.95
Allocation Granularity	B	14.57	-6.53	-8.04	N/A
Monitoring Period	C	-6.39	-3.36	9.75	N/A

Table B.47. NIPRNET Circuit Queuing Delay Second Order Interaction Effects — DBA-1

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	5.06	-16.94	27.14	-15.26
32 kbps	0.66	3.72	-9.60	5.22
64 kbps	-5.72	13.22	-17.54	10.03

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	-8.67	4.08	-8.32	12.91
10 s	-2.10	3.46	-7.56	6.20
50 s	10.77	-7.54	15.88	-19.11

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	-9.47	4.28	5.19
10 s	-6.76	3.23	3.54
50 s	16.24	-7.51	-8.72

Table B.48. NIPRNET Circuit Queuing Delay Third Order Interaction Effects — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-9.75	-4.26	14.01	3.44	1.36	-4.79	6.32	2.90	-9.22
Data Overload	9.92	6.69	-16.61	-4.31	-2.72	7.02	-5.61	-3.97	9.58
Voice Overload	-10.06	-9.04	19.10	4.94	3.97	-8.92	5.11	5.07	-10.18
Voice & Data Overload	9.89	6.61	-16.50	-4.07	-2.61	6.69	-5.82	-4.00	9.82

Table B.49. NIPRNET Circuit Queuing Delay Analysis of Variance — DBA-1

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
20960843.81	20358838.00	490299.22	19179.18	8837.24	30472.53	18448.96	11995.60	12819.29	602005.81	9953.78

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
81.44%	3.19%	1.47%	5.06%	3.06%	1.99%	2.13%	1.65%

Table B.50. SIPRNET Circuit Queuing Delay Data — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
	0.29	0.31	0.42	0.29	0.29	0.31	0.28	0.29	0.29
	0.30	0.32	0.40	0.29	0.30	0.31	0.28	0.29	0.29
All Circuits Underload	0.28	0.29	0.36	0.28	0.29	0.31	0.28	0.29	0.29
	0.28	0.31	0.31	0.29	0.29	0.30	0.28	0.29	0.29
	0.30	0.30	0.44	0.29	0.30	0.31	0.28	0.29	0.29
	0.27	0.27	0.27	0.26	0.27	0.27	0.27	0.28	0.28
	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.28
Data Overload	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.28
	0.27	0.27	0.27	0.26	0.27	0.27	0.27	0.28	0.28
	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.28
	0.43	0.41	0.50	0.39	0.39	0.41	0.38	0.38	0.38
	0.42	0.42	0.49	0.38	0.39	0.40	0.38	0.38	0.38
Voice Overload	0.41	0.41	0.51	0.38	0.38	0.42	0.38	0.38	0.39
	0.42	0.42	0.50	0.38	0.39	0.43	0.38	0.38	0.38
	0.42	0.42	0.45	0.39	0.39	0.39	0.37	0.38	0.38
	0.37	0.36	0.35	0.36	0.36	0.35	0.37	0.37	0.36
	0.37	0.36	0.35	0.37	0.36	0.35	0.37	0.37	0.35
Voice & Data Overload	0.37	0.36	0.35	0.37	0.37	0.35	0.37	0.37	0.36
	0.37	0.36	0.35	0.36	0.36	0.35	0.37	0.37	0.36
	0.37	0.36	0.35	0.37	0.36	0.35	0.37	0.37	0.36

Table B.51. SIPRNET Circuit Queuing Delay Means — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps					
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Row Sum	Row Mean	Row Effect
All Circuits Underload	0.29	0.30	0.38	0.29	0.29	0.31	0.28	0.29	0.29	2.73	0.30	-0.03
Data Overload	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.28	2.45	0.27	-0.06
Voice Overload	0.42	0.42	0.49	0.39	0.39	0.41	0.38	0.38	0.38	3.65	0.41	0.07
Voice & Data Overload	0.37	0.36	0.35	0.37	0.36	0.35	0.37	0.37	0.36	3.25	0.36	0.03
Column Sum	1.34	1.36	1.50	1.30	1.32	1.34	1.30	1.31	1.31	12.07		
Column Mean	0.34	0.34	0.37	0.33	0.33	0.33	0.32	0.33	0.33		0.34	
Column Effect	-35.42	-35.41	-35.38	-35.43	-35.42	-35.42	-35.43	-35.42	-35.42			

Table B.52. SIPRNET Circuit Queuing Delay Standard Deviations — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.009	0.009	0.053	0.003	0.004	0.004	0.001	0.001	0.000
Data Overload	0.001	0.001	0.001	0.000	0.001	0.002	0.001	0.000	0.002
Voice Overload	0.005	0.008	0.021	0.004	0.005	0.015	0.001	0.002	0.005
Voice & Data Overload	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003

Table B.53. SIPRNET Circuit Queuing Delay Difference Data — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-373.31	-373.29	-373.17	-373.31	-373.31	-373.29	-373.31	-373.31	-373.31
	-373.08	-373.06	-372.98	-373.09	-373.08	-373.06	-373.09	-373.09	-373.09
	-373.71	-373.70	-373.64	-373.71	-373.70	-373.68	-373.71	-373.70	-373.70
	-373.40	-373.38	-373.38	-373.40	-373.39	-373.39	-373.40	-373.40	-373.40
	-373.18	-373.18	-373.04	-373.19	-373.18	-373.17	-373.19	-373.19	-373.19
Data Overload	-398.68	-398.68	-398.68	-398.68	-398.68	-398.68	-398.68	-398.67	-398.67
	-399.14	-399.14	-399.14	-399.14	-399.14	-399.13	-399.13	-399.13	-399.13
	-398.81	-398.81	-398.81	-398.81	-398.81	-398.81	-398.81	-398.80	-398.80
	-399.15	-399.15	-399.15	-399.15	-399.15	-399.15	-399.15	-399.14	-399.14
	-398.88	-398.88	-398.87	-398.88	-398.87	-398.87	-398.87	-398.87	-398.87
Voice Overload	-373.19	-373.21	-373.11	-373.23	-373.23	-373.21	-373.24	-373.24	-373.23
	-373.23	-373.22	-373.16	-373.26	-373.26	-373.25	-373.27	-373.27	-373.27
	-373.39	-373.39	-373.30	-373.42	-373.43	-373.39	-373.43	-373.43	-373.42
	-373.33	-373.33	-373.25	-373.37	-373.36	-373.33	-373.38	-373.37	-373.38
	-373.31	-373.31	-373.28	-373.34	-373.34	-373.35	-373.36	-373.35	-373.35
Voice & Data Overload	-398.70	-398.71	-398.72	-398.71	-398.71	-398.72	-398.70	-398.70	-398.71
	-398.95	-398.96	-398.97	-398.95	-398.96	-398.97	-398.95	-398.95	-398.96
	-398.64	-398.64	-398.66	-398.64	-398.64	-398.66	-398.64	-398.64	-398.65
	-399.02	-399.02	-399.03	-399.02	-399.02	-399.03	-399.02	-399.02	-399.03
	-398.76	-398.76	-398.77	-398.76	-398.76	-398.77	-398.75	-398.76	-398.77

Table B.54. SIPRNET Circuit Queuing Delay Difference Means — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-373.34	-373.32	-373.24	-373.34	-373.33	-373.32	-373.34	-373.34	-373.34
Data Overload	-398.93	-398.93	-398.93	-398.94	-398.93	-398.93	-398.93	-398.92	-398.92
Voice Overload	-373.29	-373.29	-373.22	-373.33	-373.32	-373.30	-373.34	-373.33	-373.33
Voice & Data Overload	-398.82	-398.82	-398.83	-398.82	-398.82	-398.83	-398.81	-398.81	-398.82

Table B.55. SIPRNET Circuit Queuing Delay Difference Standard Deviations — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.244	0.244	0.268	0.238	0.239	0.237	0.236	0.236	0.236
Data Overload	0.207	0.206	0.207	0.207	0.207	0.207	0.207	0.206	0.205
Voice Overload	0.082	0.076	0.081	0.078	0.080	0.075	0.077	0.077	0.076
Voice & Data Overload	0.164	0.164	0.163	0.163	0.163	0.163	0.163	0.163	0.165

Table B.56. SIPRNET Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-1

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-373.57	-373.55	-373.50	-373.57	-373.56	-373.54	-373.57	-373.56	-373.56
	-373.10	-373.09	-372.99	-373.11	-373.10	-373.09	-373.12	-373.11	-373.11
Data Overload	-399.13	-399.13	-399.13	-399.13	-399.13	-399.13	-399.12	-399.12	-399.12
	-398.74	-398.73	-398.73	-398.74	-398.73	-398.73	-398.73	-398.73	-398.72
Voice Overload	-373.37	-373.37	-373.30	-373.40	-373.40	-373.38	-373.41	-373.41	-373.40
	-373.21	-373.22	-373.14	-373.25	-373.25	-373.23	-373.26	-373.26	-373.26
Voice & Data Overload	-398.97	-398.97	-398.98	-398.97	-398.97	-398.98	-398.97	-398.97	-398.98
	-398.66	-398.66	-398.67	-398.66	-398.66	-398.67	-398.66	-398.66	-398.67

Table B.57. SIPRNET Circuit Queuing Delay Main Effects — DBA-1

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-0.03	-0.06	0.07	0.03
Allocation Granularity	B	0.01	-0.01	-0.01	N/A
Monitoring Period	C	-0.01	0.00	0.01	N/A

Table B.58. SIPRNET Circuit Queuing Delay Second Order Interaction Effects — DBA-1

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	0.01	-0.02	0.02	-0.02
32 kbps	0.00	0.00	-0.01	0.00
64 kbps	-0.01	0.01	-0.02	0.01

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	-0.01	0.00	0.00	0.01
10 s	0.00	0.00	-0.01	0.01
50 s	0.01	-0.01	0.01	-0.02

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	-0.01	0.00	0.01
10 s	-0.01	0.00	0.00
50 s	0.01	-0.01	-0.01

Table B.59. SIPRNET Circuit Queuing Delay Third Order Interaction Effects — DBA-1

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-0.01	-0.01	0.02	0.00	0.00	-0.01	0.01	0.00	-0.01
Data Overload	0.01	0.01	-0.02	0.00	0.00	0.01	-0.01	0.00	0.01
Voice Overload	0.00	-0.01	0.01	0.00	0.00	0.00	0.00	0.01	-0.01
Voice & Data Overload	0.01	0.01	-0.02	0.00	0.00	0.00	-0.01	-0.01	0.01

Table B.60. SIPRNET Circuit Queuing Delay Analysis of Variance — DBA-1

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
20.84078002	20.24835738	0.481515966	0.018876171	0.009599083	0.028791473	0.016390688	0.010067255	0.011801352	0.592422637	0.015380649

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
81.28%	3.19%	1.62%	4.86%	2.77%	1.70%	1.99%	2.60%

Table B.61. Utilization Data — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	19.50	19.97	19.49	19.50	19.50	19.49	19.97	19.50	19.49
	21.12	20.88	21.12	21.12	21.12	21.12	20.88	21.12	21.12
	17.96	17.92	17.94	17.96	17.96	17.96	17.92	17.96	17.96
	18.59	18.96	18.59	18.59	18.60	18.59	18.96	18.60	18.60
	20.37	19.30	20.34	20.37	20.37	20.37	19.30	20.37	20.37
Data Overload	49.30	48.65	46.83	50.11	47.91	47.18	46.85	46.15	45.29
	48.93	49.12	47.03	50.54	48.58	47.33	47.40	45.93	46.63
	50.20	48.43	48.85	50.18	48.29	48.85	47.75	46.45	45.91
	49.16	48.87	49.06	48.43	48.65	49.06	47.11	45.87	45.92
	50.41	48.48	47.44	49.66	49.54	47.44	46.49	47.75	44.70
Voice Overload	29.09	28.32	28.32	28.73	28.91	27.31	27.55	27.48	27.50
	28.52	28.98	28.03	29.81	28.52	27.99	27.43	26.77	27.80
	29.86	27.85	28.24	29.50	27.23	27.35	27.79	27.82	27.56
	29.22	29.09	28.24	29.70	28.81	28.20	27.54	27.88	27.14
	29.45	28.79	27.80	30.51	29.43	27.84	27.42	28.54	26.74
Voice & Data Overload	47.32	47.06	48.61	47.11	46.41	48.61	46.52	46.03	46.39
	47.64	46.37	47.39	47.22	46.53	47.85	45.81	46.16	46.99
	47.74	46.57	47.58	47.30	46.72	47.85	45.55	44.69	47.15
	46.67	46.23	48.32	47.82	47.55	48.32	46.18	46.86	46.78
	47.31	46.45	47.44	47.35	47.12	47.44	46.41	46.39	46.41

Table B.62. Utilization Means — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean	Row Effect
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)			
System Underload	19.51	19.40	19.49	19.51	19.51	19.51	19.40	19.51	19.51	175.36	19.48	-16.20
Data Overload	49.60	48.71	47.84	49.78	48.59	47.97	47.12	46.43	45.69	431.74	47.97	12.29
Voice Overload	29.23	28.60	28.12	29.65	28.58	27.74	27.55	27.70	27.35	254.52	28.28	-7.40
Voice & Data Overload	47.34	46.54	47.87	47.36	46.87	48.01	46.09	46.03	46.75	422.85	46.98	11.30
Column Sum	145.68	143.25	143.33	146.30	143.55	143.23	140.17	139.67	139.30	1284.47		
Column Mean	36.42	35.81	35.83	36.58	35.89	35.81	35.04	34.92	34.82		**35.68**	
Column Effect	0.74	0.13	0.15	0.90	0.21	0.13	-0.64	-0.76	-0.86			

Table B.63. Utilization Standard Deviations — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	1.283	1.109	1.284	1.284	1.282	1.282	1.109	1.282	1.282
Data Overload	0.664	0.284	1.042	0.819	0.603	0.906	0.484	0.771	0.730
Voice Overload	0.493	0.515	0.211	0.640	0.824	0.394	0.147	0.647	0.412
Voice & Data Overload	0.419	0.319	0.559	0.270	0.465	0.456	0.406	0.811	0.341

Table B.64. Utilization Difference Data — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	6.28	6.76	6.28	6.28	6.28	6.28	6.76	6.28	6.28
	7.89	7.65	7.89	7.89	7.89	7.89	7.65	7.89	7.89
	4.62	4.57	4.60	4.62	4.62	4.62	4.57	4.62	4.62
	5.28	5.65	5.28	5.27	5.28	5.28	5.65	5.28	5.28
	7.21	6.13	7.18	7.21	7.21	7.20	6.13	7.21	7.21
Data Overload	19.73	19.08	17.26	20.54	18.34	17.61	17.28	16.58	15.72
	19.47	19.66	17.57	21.08	19.13	17.87	17.94	16.48	17.18
	20.63	18.86	19.27	20.60	18.72	19.27	18.17	16.87	16.34
	19.58	19.28	19.48	18.84	19.07	19.48	17.53	16.29	16.34
	20.94	19.01	17.97	20.18	20.06	17.97	17.02	18.28	15.23
Voice Overload	8.79	8.03	8.03	8.44	8.62	7.02	7.26	7.19	7.21
	8.18	8.63	7.68	9.46	8.18	7.65	7.08	6.42	7.45
	9.45	7.44	7.83	9.09	6.82	6.94	7.38	7.41	7.15
	8.79	8.65	7.80	9.26	8.37	7.76	7.11	7.45	6.70
	9.10	8.43	7.45	10.16	9.08	7.48	7.07	8.19	6.39
Voice & Data Overload	10.54	10.28	11.83	10.33	9.63	11.83	9.74	9.25	9.61
	11.07	9.81	10.82	10.66	9.96	11.28	9.24	9.59	10.42
	11.24	10.06	11.08	10.80	10.21	11.34	9.05	8.18	10.65
	10.16	9.72	11.80	11.30	11.04	11.80	9.67	10.35	10.27
	10.74	9.88	10.87	10.78	10.55	10.87	9.84	9.82	9.84

Table B.65. Utilization Difference Means — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	6.26	6.15	6.24	6.26	6.26	6.26	6.15	6.26	6.26
Data Overload	20.07	19.18	18.31	20.25	19.06	18.44	17.59	16.90	16.16
Voice Overload	8.86	8.24	7.76	9.28	8.21	7.37	7.18	7.33	6.98
Voice & Data Overload	10.75	9.95	11.28	10.77	10.28	11.43	9.51	9.44	10.16

Table B.66. Utilization Difference Standard Deviations — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	1.343	1.156	1.343	1.344	1.342	1.342	1.156	1.342	1.341
Data Overload	0.669	0.310	1.006	0.849	0.643	0.867	0.470	0.799	0.735
Voice Overload	0.471	0.512	0.213	0.623	0.850	0.371	0.133	0.634	0.427
Voice & Data Overload	0.428	0.223	0.499	0.352	0.541	0.399	0.343	0.808	0.425

Table B.67. Utilization Difference 90% Confidence Intervals — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	4.98	5.05	4.96	4.98	4.98	4.98	5.05	4.98	4.98
	7.54	7.25	7.52	7.54	7.54	7.53	7.25	7.54	7.54
Data Overload	19.43	18.88	17.35	19.44	18.45	17.61	17.14	16.14	15.46
	20.71	19.47	19.27	21.06	19.68	19.27	18.04	17.66	16.86
Voice Overload	8.41	7.75	7.55	8.69	7.40	7.02	7.05	6.73	6.57
	9.31	8.73	7.96	9.88	9.02	7.73	7.31	7.93	7.39
Voice & Data Overload	10.34	9.73	10.80	10.44	9.76	11.05	9.18	8.67	9.75
	11.16	10.16	11.76	11.11	10.79	11.81	9.83	10.21	10.56

Table B.68. Utilization Main Effects — DBA-2

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-16.23	12.29	-7.37	11.30
Allocation Granularity	B	0.34	0.41	-0.75	N/A
Monitoring Period	C	0.33	-0.14	-0.19	N/A

Table B.69. Utilization Second Order Interaction Effects — DBA-2

Allocation Granularity (B)	Workload (A)			
	Underload	Data	Voice	Voice/Data
8 kbps	-0.36	0.40	0.03	-0.08
32 kbps	-0.39	0.40	-0.03	0.02
64 kbps	0.74	-0.80	0.00	0.06

Monitoring Period (C)	Workload (A)			
	Underload	Data	Voice	Voice/Data
5 s	-0.34	0.53	0.20	-0.38
10 s	0.13	0.08	0.15	-0.37
50 s	0.21	-0.61	-0.35	0.75

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	0.07	0.15	-0.22
10 s	-0.07	-0.06	0.13
50 s	0.00	-0.09	0.09

Table B.70. Utilization Third Order Interaction Effects — DBA-2

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-0.02	0.01	0.00	-0.14	0.07	0.07	0.16	-0.08	-0.07
Data Overload	-0.04	0.12	-0.07	-0.02	-0.07	0.08	0.06	-0.05	-0.01
Voice Overload	-0.02	0.01	0.01	0.31	-0.03	-0.28	-0.29	0.02	0.27
Voice & Data Overload	0.08	-0.14	0.06	-0.15	0.02	0.13	0.08	0.11	-0.19

Table B.71. Utilization Analysis of Variance — DBA-2

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
256177.63	229148.62	26843.49	51.11	10.03	27.18	28.08	2.33	2.87	27029.01	63.93

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
99.31%	0.19%	0.04%	0.10%	0.10%	0.01%	0.01%	0.24%

Table B.72. Voice Circuit Queuing Delay Data — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	317.18	274.76	266.44	260.27	261.33	257.75	257.93	252.82	260.21
	317.10	283.82	388.41	265.20	262.53	300.68	259.06	256.63	274.38
	296.73	275.36	413.38	251.22	252.40	307.61	252.93	250.54	259.26
	306.94	275.10	282.69	254.81	254.93	264.84	255.06	250.78	256.88
	325.75	277.75	268.44	260.95	263.14	267.61	255.57	254.49	262.16
Data Overload	362.54	394.78	696.76	371.04	392.61	660.13	324.41	337.97	448.43
	358.97	407.14	668.17	379.57	397.43	732.94	330.53	338.12	429.52
	379.37	394.82	731.73	381.20	393.08	731.73	332.40	341.90	415.13
	365.56	401.67	767.90	362.03	391.64	767.90	323.43	337.14	442.91
	379.13	401.31	687.26	367.11	413.01	687.26	334.86	343.27	460.49
Voice Overload	219.25	226.17	346.75	221.07	231.64	264.65	239.14	252.80	329.21
	217.48	229.06	270.62	224.18	231.16	328.39	239.21	250.76	331.51
	221.95	227.04	284.00	224.32	224.52	309.26	239.00	254.34	320.76
	220.31	226.54	261.73	225.29	231.77	311.31	237.48	249.31	351.51
	220.55	229.84	292.26	226.92	230.67	322.38	239.16	260.73	307.41
Voice & Data Overload	312.66	353.66	621.34	311.31	351.98	621.34	317.98	364.86	576.93
	316.82	345.88	568.43	310.04	346.20	578.36	314.89	358.89	604.23
	314.10	354.85	577.60	313.76	356.35	618.88	318.53	346.09	566.75
	307.94	343.96	591.65	312.90	359.09	591.65	320.81	362.19	552.12
	315.31	353.16	553.96	310.28	360.85	553.96	322.00	366.61	548.75

Table B.73. Voice Circuit Queuing Delay Means — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean	Row Effect
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)			
System Underload	312.74	277.36	323.87	258.49	258.87	279.70	256.11	253.05	262.58	2482.76	275.86	-74.99
Data Overload	369.11	399.94	710.36	372.19	397.55	715.99	329.13	339.68	439.30	4073.26	452.58	101.73
Voice Overload	219.90	227.73	291.07	224.36	229.95	307.20	238.80	253.59	328.08	2320.67	257.85	-93.00
Voice & Data Overload	313.37	350.30	582.59	311.66	354.89	592.84	318.84	359.73	569.76	3753.98	417.11	66.26
Column Sum	1215.12	1255.33	1907.90	1166.69	1241.27	1895.72	1142.88	1206.05	1599.71	12630.68		
Column Mean	303.78	313.83	476.98	291.67	310.32	473.93	285.72	301.51	399.93		**350.85**	
Column Effect	-47.07	-37.02	126.12	-59.18	-40.54	123.08	-65.13	-49.34	49.08			

Table B.74. Voice Circuit Queuing Delay Standard Deviations — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	11.159	3.801	71.140	5.490	4.873	22.738	2.426	2.569	6.866
Data Overload	9.542	5.234	39.580	8.155	8.921	42.356	5.006	2.721	17.502
Voice Overload	1.664	1.626	33.283	2.135	3.069	25.054	0.740	4.431	16.145
Voice & Data Overload	3.400	4.997	25.636	1.630	5.901	28.341	2.750	8.164	22.367

Table B.75. Voice Circuit Queuing Delay Difference Data — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	56.95	14.52	6.20	0.04	1.09	-2.48	-2.31	-7.41	-0.02
	56.77	23.49	128.08	4.87	2.20	40.35	-1.27	-3.70	14.05
	36.32	14.95	152.97	-9.19	-8.01	47.20	-7.48	-9.87	-1.15
	46.87	15.03	22.62	-5.26	-5.14	4.77	-5.02	-9.30	-3.19
	65.29	17.29	7.98	0.49	2.68	7.14	-4.90	-5.97	1.70
Data Overload	102.09	134.33	436.31	110.58	132.15	399.67	63.96	77.52	187.98
	98.91	147.09	408.11	119.52	137.38	472.89	70.48	78.07	169.47
	118.75	134.19	471.11	120.57	132.46	471.11	71.78	81.28	154.51
	105.50	141.61	507.84	101.97	131.58	507.84	63.37	77.09	182.85
	118.66	140.85	426.79	106.64	152.54	426.79	74.40	82.81	200.03
Voice Overload	-89.76	-82.84	37.74	-87.94	-77.37	-44.36	-69.87	-56.21	20.20
	-91.92	-80.33	-38.77	-85.22	-78.24	18.99	-70.19	-58.63	22.11
	-86.96	-81.87	-24.91	-84.59	-84.39	0.35	-69.91	-54.57	11.85
	-88.96	-82.73	-47.54	-83.97	-77.49	2.05	-71.78	-59.95	42.24
	-88.60	-79.31	-16.89	-82.24	-78.48	13.23	-70.00	-48.42	-1.74
Voice & Data Overload	3.43	44.43	312.11	2.08	42.75	312.11	8.75	55.63	267.71
	7.55	36.61	259.15	0.76	36.93	269.09	5.62	49.62	294.96
	4.64	45.39	268.14	4.30	46.89	309.42	9.07	36.63	257.29
	-1.38	34.65	282.34	3.59	49.78	282.34	11.50	52.88	242.81
	5.83	43.68	244.48	0.80	51.37	244.48	12.52	57.14	239.27

Table B.76. Voice Circuit Queuing Delay Difference Means — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	52.44	17.06	63.57	-1.81	-1.43	19.40	-4.19	-7.25	2.28
Data Overload	108.78	139.61	450.03	111.86	137.22	455.66	68.80	79.35	178.97
Voice Overload	-89.24	-81.42	-18.07	-84.79	-79.20	-1.95	-70.35	-55.56	18.93
Voice & Data Overload	4.02	40.95	273.24	2.31	45.54	283.49	9.49	50.38	260.41

Table B.77. Voice Circuit Queuing Delay Difference Standard Deviations — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	11.126	3.757	71.085	5.469	4.834	22.666	2.455	2.515	6.819
Data Overload	9.352	5.447	39.598	8.080	8.874	42.504	4.896	2.540	17.524
Voice Overload	1.810	1.547	33.392	2.081	2.944	24.944	0.812	4.504	16.067
Voice & Data Overload	3.377	4.947	25.716	1.606	5.825	28.380	2.687	8.204	22.434

Table B.78. Voice Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	41.83	13.47	-4.21	-7.02	-6.04	-2.21	-6.53	-9.65	-4.23
	63.05	20.64	131.35	3.40	3.17	41.01	-1.85	-4.85	8.78
Data Overload	99.87	134.42	412.28	104.15	128.76	415.13	64.13	76.93	162.26
	117.70	144.81	487.79	119.56	145.68	496.19	73.47	81.77	195.68
Voice Overload	-90.97	-82.89	-49.91	-86.77	-82.00	-25.73	-71.12	-59.85	3.61
	-87.51	-79.94	13.76	-82.81	-76.39	21.83	-69.57	-51.26	34.25
Voice & Data Overload	0.80	36.23	248.72	0.78	39.99	256.43	6.93	42.56	239.02
	7.24	45.67	297.76	3.84	51.10	310.55	12.05	58.20	281.80

Table B.79. Voice Circuit Queuing Delay Main Effects — DBA-2

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-74.99	101.73	-93.00	66.26
Allocation Granularity	B	14.01	7.79	-21.80	N/A
Monitoring Period	C	-57.13	-42.30	99.43	N/A

Table B.80. Voice Circuit Queuing Delay Second Order Interaction Effects — DBA-2

Allocation Granularity (B)	Workload (A)			
	Underload	Data	Voice	Voice/Data
8 kbps	14.78	26.54	-25.63	-15.70
32 kbps	-17.96	34.87	-11.81	-5.10
64 kbps	3.18	-61.42	37.43	20.80

Monitoring Period (C)	Workload (A)			
	Underload	Data	Voice	Voice/Data
5 s	57.05	-38.65	26.96	-45.36
10 s	29.53	-31.23	21.54	-19.84
50 s	-86.57	69.87	-48.50	65.20

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	-3.95	-9.84	13.79
10 s	-8.73	-6.03	14.76
50 s	12.69	15.86	-28.55

Table B.81. Voice Circuit Queuing Delay Third Order Interaction Effects — DBA-2

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	12.12	-5.80	-6.32	2.73	11.98	-14.71	-14.85	-6.18	21.03
Data Overload	-24.30	-10.94	35.24	-17.44	-18.14	35.58	41.74	29.08	-70.82
Voice Overload	7.79	10.99	-18.78	10.53	2.90	-13.43	-18.32	-13.89	32.21
Voice & Data Overload	4.39	5.75	-10.13	4.19	3.26	-7.44	-8.57	-9.00	17.58

Table B.82. Voice Circuit Queuing Delay Analysis of Variance — DBA-2

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
25150876.40	22157498.63	1305526.15	43929.89	896292.05	137199.85	438232.61	37217.04	79224.64	2993377.77	55755.54

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
43.61%	1.47%	29.94%	4.58%	14.64%	1.24%	2.65%	1.86%

Table B.83. Video Circuit Queuing Delay Data — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	303.35	368.64	1995.46	266.16	342.03	1808.90	228.37	357.97	1655.04
	252.59	373.41	1676.96	279.69	271.13	837.97	228.61	305.32	585.17
	305.42	507.81	2558.22	306.18	306.70	778.61	226.98	421.92	280.49
	260.09	326.16	1668.98	255.40	345.55	1932.63	228.46	325.86	1010.54
	348.36	460.85	2257.51	300.79	368.93	1825.66	228.43	360.17	637.73
Data Overload	280.67	296.84	2404.90	289.55	589.11	3325.47	227.79	334.79	2033.98
	335.83	424.20	2718.66	307.85	418.29	1296.22	228.60	321.61	1038.00
	343.68	440.30	2579.79	390.00	631.47	2579.79	226.46	446.74	940.83
	310.09	499.34	2105.24	429.58	617.29	2105.24	227.86	607.72	1603.77
	450.82	704.80	1930.49	333.04	331.15	1930.49	228.04	294.11	1331.51
Voice Overload	475.26	1437.83	4258.26	440.12	1195.57	3953.97	436.21	888.30	3904.58
	476.39	1099.44	5733.91	469.66	1417.43	6940.87	447.65	949.52	3416.93
	487.27	1606.58	5125.98	452.40	2671.39	6189.54	428.39	1177.93	2651.19
	443.06	1749.26	5785.14	485.15	2104.97	3687.30	443.22	1407.10	3509.14
	485.68	1622.87	6508.93	494.32	1230.65	4359.33	437.28	1568.52	2062.87
Voice & Data Overload	814.32	1259.66	4926.38	472.01	1460.59	4926.38	479.83	1071.02	4893.39
	969.26	1347.47	4420.79	481.17	1494.14	5422.27	465.52	1352.29	4145.35
	939.91	1345.05	4653.65	457.35	1822.71	4765.02	461.81	1536.73	4124.69
	892.39	1355.69	5047.73	491.42	1793.21	5047.73	479.23	644.66	5689.69
	761.05	1981.72	5419.19	469.54	2549.83	5419.19	475.42	952.77	4826.17

Table B.84. Video Circuit Queuing Delay Means — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	
System Underload	293.96	407.37	2031.42	281.64	326.87	1436.76	228.17	354.25	833.79	6194.24
Data Overload	344.22	473.10	2347.82	350.00	517.46	2247.44	227.75	400.99	1389.62	8298.40
Voice Overload	473.53	1503.20	5482.44	468.33	1724.00	5026.20	438.55	1198.27	3108.94	19423.47
Voice & Data Overload	875.39	1457.92	4893.55	474.30	1824.10	5116.12	472.36	1111.50	4735.86	20961.08
Column Sum	1987.10	3841.58	14755.23	1574.27	4392.43	13826.52	1366.83	3065.01	10068.21	54877.19
Column Mean	496.77	960.40	3688.81	393.57	1098.11	3456.63	341.71	766.25	2517.05	
Column Effect	-1027.59	-563.97	2164.44	-1130.80	-426.26	1932.26	-1182.66	-758.11	992.69	

Table B.85. Video Circuit Queuing Delay Standard Deviations — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	38.851	74.495	383.058	21.799	38.279	576.048	0.670	44.238	527.277
Data Overload	64.493	149.085	326.955	58.422	134.764	757.972	0.786	129.362	444.266
Voice Overload	17.860	251.422	841.756	22.418	644.070	1449.686	7.329	291.148	740.248
Voice & Data Overload	86.699	295.409	381.511	12.801	438.365	295.605	8.223	347.697	645.173

Table B.86. Video Circuit Queuing Delay Difference Data — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
	-32.78	32.51	1659.33	-69.97	5.90	1472.77	-107.76	21.84	1318.91
	-82.64	38.18	1341.73	-55.54	-64.09	502.75	-106.62	-29.91	249.94
System Underload	-29.59	172.80	2223.20	-28.84	-28.31	443.60	-108.03	86.90	-54.53
	-75.89	-9.82	1333.00	-80.58	9.57	1596.65	-107.51	-10.12	674.56
	15.78	128.27	1924.92	-31.80	36.35	1493.08	-104.16	27.58	305.14
	-53.99	-37.82	2070.24	-45.12	254.45	2990.80	-106.88	0.12	1699.32
	-0.21	88.17	2382.62	-28.19	82.25	960.19	-107.44	-14.43	701.96
Data Overload	7.89	104.51	2244.00	54.21	295.68	2244.00	-109.33	110.95	605.04
	-24.38	164.86	1770.77	95.10	282.81	1770.77	-106.62	273.24	1269.30
	115.94	369.92	1595.61	-1.84	-3.73	1595.61	-106.84	-40.77	996.63
	138.78	1101.35	3921.78	103.64	859.08	3617.49	99.73	551.82	3568.10
	141.37	764.42	5398.89	134.64	1082.42	6605.85	112.63	614.51	3081.92
Voice Overload	152.70	1272.01	4791.41	117.83	2336.82	5854.97	93.82	843.36	2316.62
	106.61	1412.82	5448.69	148.71	1768.52	3350.85	106.77	1070.66	3172.69
	149.68	1286.87	6172.93	158.32	894.65	4023.33	101.28	1232.52	1726.87
	481.52	926.86	4593.59	139.22	1127.79	4593.59	147.03	738.23	4560.59
	634.04	1012.25	4085.58	145.95	1158.93	5087.05	130.30	1017.08	3810.14
Voice & Data Overload	603.65	1008.79	4317.39	121.09	1486.45	4428.76	125.55	1200.47	3788.43
	556.62	1019.91	4711.96	155.64	1457.43	4711.96	143.46	308.89	5353.91
	424.91	1645.58	5083.05	133.39	2213.69	5083.05	139.28	616.63	4490.03

Table B.87. Video Circuit Queuing Delay Difference Means — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-41.02	72.39	1696.44	-53.34	-8.12	1101.77	-106.82	19.26	498.80
Data Overload	9.05	137.93	2012.65	14.83	182.29	1912.27	-107.42	65.82	1054.45
Voice Overload	137.83	1167.49	5146.74	132.63	1388.30	4690.50	102.85	862.57	2773.24
Voice & Data Overload	540.15	1122.68	4558.31	139.06	1488.86	4780.88	137.12	776.26	4400.62

Table B.88. Video Circuit Queuing Delay Difference Standard Deviations — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	39.912	75.372	383.722	22.846	38.818	576.127	1.577	44.531	526.562
Data Overload	64.431	149.186	326.400	58.560	134.889	758.294	1.107	129.593	444.852
Voice Overload	18.367	251.097	841.813	22.262	644.512	1450.490	7.155	290.962	739.940
Voice & Data Overload	86.367	294.744	381.355	13.015	437.493	295.326	8.992	347.604	645.330

Table B.89. Video Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-79.08	0.52	1330.57	-75.13	-45.13	552.46	-108.32	-23.20	-3.25
	-2.97	144.25	2062.30	-31.56	28.90	1651.08	-105.31	61.72	1000.86
Data Overload	-52.38	-4.32	1701.44	-41.00	53.68	1189.27	-108.48	-57.74	630.30
	70.48	280.17	2323.86	70.67	310.90	2635.28	-106.37	189.38	1478.60
Voice Overload	120.32	928.08	4344.11	111.40	773.78	3307.51	96.02	585.15	2067.74
	155.34	1406.90	5949.37	153.85	2002.82	6073.48	109.67	1139.99	3478.74
Voice & Data Overload	457.80	841.65	4194.71	126.65	1071.73	4499.30	128.55	444.83	3785.32
	622.49	1403.71	4921.92	151.47	1905.99	5062.46	145.70	1107.69	5015.91

Table B.90. Video Circuit Queuing Delay Main Effects — DBA-2

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-836.12	-602.32	633.80	804.64
Allocation Granularity	B	190.96	125.07	-316.03	N/A
Monitoring Period	C	-1113.68	-582.78	1696.46	N/A

Table B.91. Video Circuit Queuing Delay Second Order Interaction Effects — DBA-2

Allocation Granularity (B)	Workload (A)			
	Underload	Data	Voice	Voice/Data
8 kbps	31.71	-57.96	137.27	-111.02
32 kbps	-131.56	-8.81	122.95	17.43
64 kbps	99.85	66.77	-260.21	93.59

Monitoring Period (C)	Workload (A)			
	Underload	Data	Voice	Voice/Data
5 s	693.36	498.96	-584.34	-607.98
10 s	257.36	124.59	-100.22	-281.72
50 s	-950.72	-623.55	684.57	889.70

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	-104.87	-142.18	247.05
10 s	-172.15	31.45	140.70
50 s	277.02	110.73	-387.75

Table B.92. Video Circuit Queuing Delay Third Order Interaction Effects — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-91.77	-5.98	97.74	162.39	-60.92	-101.47	-70.63	66.90	3.73
Data Overload	8.76	48.40	-57.16	68.61	-94.10	25.49	-77.37	45.70	31.67
Voice Overload	-209.96	-128.04	338.00	-97.64	-30.62	128.26	307.60	158.66	-466.26
Voice & Data Overload	292.96	85.62	-378.59	-133.36	185.64	-52.28	-159.60	-271.27	430.87

Table B.93. Video Circuit Queuing Delay Analysis of Variance — DBA-2

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
895176425.49	418264644.98	94996480.13	9118922.34	267474899.59	2388540.27	62472980.45	7640378.77	6059273.92	476911780.51	26760305.03

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
19.92%	1.91%	56.08%	0.50%	13.10%	1.60%	1.27%	5.61%

Table B.94. NIPRNET Circuit Queuing Delay Data — DBA-2

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	283.22	306.99	362.40	286.98	295.73	305.94	280.80	287.98	290.00
	289.06	317.71	425.85	288.12	296.20	308.37	280.37	287.65	288.84
	279.08	289.10	320.49	285.63	288.03	291.38	279.61	286.84	288.00
	286.87	299.44	361.53	285.81	290.87	297.24	280.73	287.18	288.74
	289.17	303.20	382.42	288.04	296.07	309.47	279.04	287.13	289.24
Data Overload	270.12	271.58	272.67	269.46	271.47	271.52	275.65	278.64	280.08
	269.34	272.85	272.43	269.00	273.57	270.79	276.19	277.79	282.49
	270.13	271.04	273.48	269.09	270.04	273.48	276.58	278.14	287.30
	268.65	271.03	276.49	266.82	271.50	276.49	276.71	278.51	280.97
	269.99	271.18	271.70	269.29	271.79	271.70	275.76	280.55	279.87
Voice Overload	412.08	427.05	508.50	379.45	387.14	412.66	375.19	380.73	386.05
	403.24	417.54	489.84	385.12	383.18	385.28	373.87	377.29	383.40
	414.68	410.71	547.09	383.45	380.57	406.81	374.47	378.69	389.56
	416.08	426.14	497.11	383.63	386.44	386.64	375.31	377.61	390.88
	413.36	423.30	500.66	385.43	393.19	403.77	375.37	376.06	385.66
Voice & Data Overload	371.66	367.05	351.78	370.13	367.58	351.78	372.44	369.17	357.25
	371.21	367.50	352.91	371.11	366.85	353.23	372.82	370.30	359.73
	372.52	367.34	362.85	372.07	367.46	356.61	372.51	369.74	358.40
	371.05	367.30	352.73	370.59	367.97	352.73	373.61	369.38	360.54
	371.14	367.10	354.50	369.93	367.13	354.50	373.42	369.57	359.03

Table B.95. NIPRNET Circuit Queuing Delay Means — DBA-2

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Row Sum
System Underload	285.48	303.29	370.54	286.92	293.38	302.48	280.11	287.36	288.96	2698.51
Data Overload	269.65	271.54	273.35	268.73	271.68	272.80	276.18	278.73	282.14	2464.78
Voice Overload	411.89	420.95	508.64	383.42	386.11	399.03	374.84	378.08	387.11	3650.06
Voice & Data Overload	371.52	367.26	354.95	370.77	367.40	353.77	372.96	369.63	358.99	3287.24
Column Sum	1338.53	1363.03	1507.49	1309.83	1318.56	1328.08	1304.09	1313.79	1317.20	12100.60
Column Mean	334.63	340.76	376.87	327.46	329.64	332.02	326.02	328.45	329.30	
Column Effect	-1.49	4.63	40.74	-8.67	-6.49	-4.11	-10.11	-7.68	-6.83	

Table B.96. NIPRNET Circuit Queuing Delay Standard Deviations — DBA-2

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	4.313	10.464	38.252	1.185	3.732	7.845	0.763	0.452	0.733
Data Overload	0.643	0.766	1.863	1.084	1.262	2.287	0.474	1.074	3.066
Voice Overload	5.057	6.821	22.518	2.385	4.757	12.362	0.653	1.758	3.053
Voice & Data Overload	0.610	0.183	4.521	0.859	0.428	1.868	0.528	0.431	1.257

Table B.97. NIPRNET Circuit Queuing Delay Difference Data — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-90.84	-67.07	-11.67	-87.09	-78.33	-68.12	-93.26	-86.09	-84.07
	-85.40	-56.75	51.39	-86.33	-78.25	-66.09	-94.09	-86.81	-85.62
	-94.39	-84.37	-52.97	-87.84	-85.44	-82.08	-93.86	-86.63	-85.47
	-86.58	-74.01	-11.91	-87.64	-82.58	-76.20	-92.71	-86.26	-84.70
	-83.85	-69.83	9.40	-84.98	-76.96	-63.55	-93.98	-85.89	-83.78
Data Overload	-128.97	-127.51	-126.42	-129.63	-127.61	-127.57	-123.44	-120.45	-119.01
	-129.94	-126.43	-126.85	-130.27	-125.70	-128.48	-123.09	-121.49	-116.79
	-129.06	-128.14	-125.71	-130.10	-129.15	-125.71	-122.61	-121.05	-111.88
	-130.50	-128.13	-122.67	-132.34	-127.66	-122.67	-122.45	-120.65	-118.19
	-129.10	-127.91	-127.38	-129.79	-127.29	-127.38	-123.33	-118.53	-119.22
Voice Overload	38.33	53.29	134.75	5.69	13.38	38.90	1.44	6.98	12.29
	29.54	43.84	116.14	11.42	9.48	11.57	0.16	3.59	9.69
	40.89	36.92	173.29	9.65	6.78	33.01	0.68	4.90	15.77
	42.69	52.75	123.72	10.24	13.06	13.25	1.92	4.22	17.49
	39.58	49.52	126.88	11.65	19.41	29.98	1.58	2.27	11.88
Voice & Data Overload	-27.61	-32.22	-47.49	-29.14	-31.69	-47.49	-26.82	-30.10	-42.02
	-27.88	-31.60	-46.18	-27.98	-32.24	-45.87	-26.27	-28.79	-39.37
	-26.47	-31.65	-36.15	-26.93	-31.54	-42.38	-26.48	-29.26	-40.60
	-27.98	-31.72	-46.30	-28.44	-31.05	-46.30	-25.42	-29.65	-38.48
	-28.06	-32.10	-44.70	-29.27	-32.07	-44.70	-25.78	-29.64	-40.18

Table B.98. NIPRNET Circuit Queuing Delay Difference Means — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-88.21	-70.41	-3.15	-86.78	-80.31	-71.21	-93.58	-86.34	-84.73
Data Overload	-129.51	-127.62	-125.81	-130.43	-127.48	-126.36	-122.98	-120.43	-117.02
Voice Overload	38.21	47.26	134.96	9.73	12.42	25.35	1.16	4.39	13.43
Voice & Data Overload	-27.60	-31.86	-44.16	-28.35	-31.72	-45.35	-26.16	-29.49	-40.13

Table B.99. NIPRNET Circuit Queuing Delay Difference Standard Deviations — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	4.319	10.074	37.960	1.159	3.564	7.707	0.582	0.377	0.819
Data Overload	0.678	0.715	1.857	1.098	1.228	2.294	0.437	1.134	3.025
Voice Overload	5.105	6.898	22.447	2.403	4.760	12.247	0.717	1.740	3.149
Voice & Data Overload	0.652	0.283	4.589	0.954	0.467	1.933	0.560	0.490	1.331

Table B.100. NIPRNET Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-2

Offered Load	Allocation Granularity: 8 kbps Monitoring Period (5)	Allocation Granularity: 8 kbps Monitoring Period (10)	Allocation Granularity: 8 kbps Monitoring Period (50)	Allocation Granularity: 32 kbps Monitoring Period (5)	Allocation Granularity: 32 kbps Monitoring Period (10)	Allocation Granularity: 32 kbps Monitoring Period (50)	Allocation Granularity: 64 kbps Monitoring Period (5)	Allocation Granularity: 64 kbps Monitoring Period (10)	Allocation Granularity: 64 kbps Monitoring Period (50)
System Underload	-92.33 -84.09	-80.01 -60.80	-39.35 33.04	-87.88 -85.67	-83.71 -76.91	-78.56 -63.86	-94.14 -93.03	-86.70 -85.98	-85.51 -83.95
Data Overload	-130.16 -128.87	-128.31 -126.94	-127.58 -124.04	-131.47 -129.38	-128.65 -126.31	-128.55 -124.18	-123.40 -122.57	-121.51 -119.35	-119.90 -114.13
Voice Overload	33.34 43.07	40.69 53.84	113.55 156.36	7.44 12.02	7.88 16.96	13.67 37.02	0.47 1.84	2.73 6.05	10.42 16.43
Voice & Data Overload	-28.22 -26.98	-32.13 -31.59	-48.54 -39.79	-29.26 -27.44	-32.16 -31.27	-47.19 -43.50	-26.69 -25.62	-29.95 -29.02	-41.40 -38.86

Table B.101. NIPRNET Circuit Queuing Delay Main Effects — DBA-2

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-36.29	-62.26	69.43	29.12
Allocation Granularity	B	14.63	-6.42	-8.20	N/A
Monitoring Period	C	-6.76	-3.18	9.94	N/A

Table B.102. NIPRNET Circuit Queuing Delay Second Order Interaction Effects — DBA-2

Allocation Granularity (B)	Workload (A) Underload	Data	Voice	Voice/Data
8 kbps	5.31	-16.98	26.97	-15.30
32 kbps	0.85	3.63	-9.62	5.15
64 kbps	-6.15	13.35	-17.35	10.15

Monitoring Period (C)	Workload (A) Underload	Data	Voice	Voice/Data
5 s	-8.91	4.41	-8.76	13.26
10 s	-1.98	3.29	-7.34	6.03
50 s	10.89	-7.70	16.10	-19.28

Monitoring Period (C)	Allocation Granularity (B) 8 kbps	32 kbps	64 kbps
5 s	-9.36	4.51	4.86
10 s	-6.82	3.11	3.70
50 s	16.18	-7.62	-8.56

Table B.103. NIPRNET Circuit Queuing Delay Third Order Interaction Effects — DBA-2

Offered Load	Allocation Granularity: 8 kbps Monitoring Period (5)	Allocation Granularity: 8 kbps Monitoring Period (10)	Allocation Granularity: 8 kbps Monitoring Period (50)	Allocation Granularity: 32 kbps Monitoring Period (5)	Allocation Granularity: 32 kbps Monitoring Period (10)	Allocation Granularity: 32 kbps Monitoring Period (50)	Allocation Granularity: 64 kbps Monitoring Period (5)	Allocation Granularity: 64 kbps Monitoring Period (10)	Allocation Granularity: 64 kbps Monitoring Period (50)
System Underload	-9.26	-4.50	13.76	3.81	1.17	-4.98	5.44	3.34	-8.78
Data Overload	9.84	6.73	-16.57	-4.50	-2.62	7.12	-5.35	-4.11	9.45
Voice Overload	-10.39	-8.88	19.27	4.90	3.99	-8.90	5.49	4.88	-10.37
Voice & Data Overload	9.81	6.65	-16.46	-4.22	-2.54	6.76	-5.59	-4.11	9.70

Table B.104. NIPRNET Circuit Queuing Delay Analysis of Variance — DBA-2

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
20938221.39	20336729.14	488839.17	19348.59	9269.53	30467.03	18973.65	11893.57	12728.07	601492.25	9972.64

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
81.27%	3.22%	1.54%	5.07%	3.15%	1.98%	2.12%	1.66%

Table B.105. SIPRNET Circuit Queuing Delay Data — DBA-2

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	288.15	307.70	423.65	287.20	291.57	309.52	281.12	287.74	288.89
	297.22	316.08	395.04	289.98	298.24	312.02	281.19	288.03	289.31
	278.22	290.91	355.65	283.63	289.01	309.03	279.04	285.97	288.24
	282.35	305.23	309.50	285.78	294.13	300.97	280.08	287.00	289.17
	297.92	301.79	439.44	290.74	296.86	306.50	280.61	287.41	289.00
Data Overload	266.23	269.27	271.24	264.97	268.83	273.16	272.57	276.95	277.05
	265.28	270.56	271.01	265.54	268.96	274.46	272.83	277.74	281.59
	267.00	268.96	273.09	265.66	270.17	273.09	274.36	277.58	281.76
	265.97	270.37	269.81	264.58	268.72	269.81	273.35	277.33	282.39
	265.90	269.08	271.83	265.23	270.59	271.83	272.34	277.46	278.75
Voice Overload	411.12	407.19	503.24	385.69	389.69	409.08	376.11	376.54	383.63
	407.75	424.77	493.46	384.60	387.34	401.42	375.99	380.57	380.08
	423.98	414.04	505.60	384.85	379.85	416.23	374.45	380.41	388.99
	414.19	424.05	498.00	381.04	389.69	425.58	375.70	378.34	376.83
	416.42	424.09	453.87	393.19	392.78	385.34	375.08	378.58	382.27
Voice & Data Overload	365.87	364.49	351.12	364.87	363.20	351.12	368.33	367.55	362.32
	365.65	364.04	351.12	364.53	363.82	351.91	368.08	366.07	354.43
	366.74	364.77	351.32	364.82	365.66	351.86	367.13	365.11	356.28
	365.05	363.34	352.97	365.35	364.85	352.97	368.30	366.73	355.41
	366.13	363.87	352.14	364.86	364.06	352.14	367.52	366.02	356.54

Table B.106. SIPRNET Circuit Queuing Delay Means — DBA-2

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Row Sum
System Underload	288.77	304.34	384.65	287.46	293.96	307.61	280.41	287.23	288.92	2723.36
Data Overload	266.08	269.65	271.40	265.19	269.45	272.47	273.09	277.41	280.31	2445.04
Voice Overload	414.69	418.83	490.83	385.87	387.87	407.53	375.47	378.89	382.36	3642.34
Voice & Data Overload	365.89	364.10	351.73	364.88	364.32	352.00	367.87	366.30	357.00	3254.09
Column Sum	1335.43	1356.92	1498.62	1303.42	1315.60	1339.61	1296.84	1309.82	1308.59	12064.84
Column Mean	333.86	339.23	374.65	325.85	328.90	334.90	324.21	327.46	327.15	
Column Effect	-1.28	4.09	39.52	-9.28	-6.23	-0.23	-10.93	-7.68	-7.99	

Table B.107. SIPRNET Circuit Queuing Delay Standard Deviations — DBA-2

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	8.774	9.174	52.725	2.942	3.775	4.198	0.884	0.804	0.413
Data Overload	0.623	0.756	1.199	0.440	0.862	1.756	0.804	0.302	2.299
Voice Overload	6.133	7.885	21.195	4.460	4.881	15.278	0.692	1.661	4.510
Voice & Data Overload	0.620	0.556	0.809	0.296	0.955	0.663	0.526	0.907	3.089

Table B.108. SIPRNET Circuit Queuing Delay Difference Data — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-85.44	-65.90	50.05	-86.40	-82.03	-64.07	-92.48	-85.85	-84.71
	-76.16	-57.30	21.67	-83.40	-75.14	-61.36	-92.19	-85.34	-84.07
	-95.77	-83.08	-18.34	-90.36	-84.98	-64.96	-94.95	-88.02	-85.75
	-91.34	-68.45	-64.19	-87.91	-79.56	-72.72	-93.61	-86.69	-84.52
	-75.56	-71.69	65.96	-82.74	-76.61	-66.98	-92.87	-86.07	-84.48
Data Overload	-132.72	-129.68	-127.71	-133.98	-130.12	-125.79	-126.38	-122.00	-121.90
	-134.13	-128.85	-128.40	-133.87	-130.45	-124.94	-126.58	-121.66	-117.82
	-132.08	-130.12	-125.99	-133.42	-128.91	-125.99	-124.72	-121.50	-117.32
	-133.45	-129.05	-129.61	-134.84	-130.70	-129.61	-126.07	-122.09	-117.03
	-133.25	-130.07	-127.32	-133.92	-128.56	-127.32	-126.81	-121.69	-120.40
Voice Overload	37.51	33.57	129.62	12.07	16.07	35.46	2.49	2.92	10.02
	34.10	51.12	119.81	10.95	13.69	27.77	2.34	6.92	6.43
	50.17	40.23	131.79	11.04	6.04	42.42	0.64	6.60	15.18
	40.44	50.30	124.24	7.29	15.93	51.82	1.95	4.59	3.08
	42.69	50.36	80.13	19.46	19.05	11.61	1.35	4.85	8.54
Voice & Data Overload	-33.20	-34.58	-47.95	-34.20	-35.87	-47.95	-30.74	-31.52	-36.75
	-33.66	-35.28	-48.20	-34.79	-35.50	-47.41	-31.24	-33.25	-44.88
	-32.27	-34.23	-47.69	-34.19	-33.35	-47.15	-31.87	-33.90	-42.73
	-34.34	-36.04	-46.41	-34.03	-34.54	-46.41	-31.08	-32.66	-43.98
	-32.99	-35.25	-46.98	-34.27	-35.06	-46.98	-31.60	-33.10	-42.59

Table B.109. SIPRNET Circuit Queuing Delay Difference Means — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-84.85	-69.28	11.03	-86.16	-79.66	-66.02	-93.22	-86.40	-84.70
Data Overload	-133.13	-129.56	-127.81	-134.01	-129.75	-126.73	-126.11	-121.79	-118.89
Voice Overload	40.98	45.12	117.12	12.16	14.16	33.82	1.75	5.18	8.65
Voice & Data Overload	-33.29	-35.08	-47.45	-34.30	-34.86	-47.18	-31.31	-32.88	-42.18

Table B.110. SIPRNET Circuit Queuing Delay Difference Standard Deviations — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	8.994	9.379	52.853	3.165	3.990	4.257	1.104	1.030	0.629
Data Overload	0.771	0.581	1.337	0.518	0.956	1.821	0.824	0.246	2.146
Voice Overload	6.064	7.867	21.198	4.464	4.920	15.255	0.761	1.627	4.486
Voice & Data Overload	0.770	0.700	0.735	0.290	0.983	0.563	0.443	0.883	3.182

Table B.111. SIPRNET Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-2

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-93.43	-78.23	-39.36	-89.18	-83.47	-70.08	-94.27	-87.38	-85.30
	-76.28	-60.34	61.42	-83.14	-75.86	-61.96	-92.17	-85.41	-84.10
Data Overload	-133.86	-130.11	-129.08	-134.50	-130.66	-128.47	-126.90	-122.02	-120.94
	-132.39	-129.00	-126.53	-133.51	-128.84	-124.99	-125.33	-121.55	-116.84
Voice Overload	35.20	37.62	96.91	7.90	9.47	19.27	1.03	3.63	4.37
	46.76	52.62	137.33	16.42	18.85	48.36	2.48	6.73	12.93
Voice & Data Overload	-34.03	-35.75	-48.15	-34.57	-35.80	-47.72	-31.73	-33.73	-45.22
	-32.56	-34.41	-46.75	-34.02	-33.93	-46.64	-30.89	-32.04	-39.15

Table B.112. SIPRNET Circuit Queuing Delay Main Effects — DBA-2

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-32.54	-63.46	69.57	26.43
Allocation Granularity	B	14.11	-5.25	-8.86	N/A
Monitoring Period	C	-7.16	-3.27	10.43	N/A

Table B.113. SIPRNET Circuit Queuing Delay Second Order Interaction Effects — DBA-2

Allocation Granularity (B)	Workload (A)			
	Underload	Data	Voice	Voice/Data
8 kbps	9.21	-16.75	22.63	-15.10
32 kbps	-1.00	2.62	-5.70	4.08
64 kbps	-8.21	14.13	-16.94	11.02

Monitoring Period (C)	Workload (A)			
	Underload	Data	Voice	Voice/Data
5 s	-9.89	3.61	-5.53	11.81
10 s	-4.15	3.77	-6.24	6.61
50 s	14.03	-7.38	11.77	-18.42

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	-8.23	3.13	5.10
10 s	-6.75	2.29	4.46
50 s	14.97	-5.42	-9.56

Table B.114. SIPRNET Circuit Queuing Delay Third Order Interaction Effects — DBA-2

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-11.87	-7.42	19.29	5.04	2.75	-7.79	6.84	4.67	-11.51
Data Overload	8.82	6.85	-15.67	-3.42	-2.37	5.79	-5.39	-4.48	9.88
Voice Overload	-5.84	-6.37	12.20	1.68	1.33	-3.01	4.16	5.03	-9.19
Voice & Data Overload	8.89	6.93	-15.83	-3.30	-1.71	5.01	-5.60	-5.22	10.82

Table B.115. SIPRNET Circuit Queuing Delay Analysis of Variance — DBA-2

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
20805582.43	20216710.09	478120.48	18317.24	10250.27	27571.57	16862.80	10379.72	11935.23	588872.35	15435.03

Var Due to Workload	Var Due to Allocation Granularity	Var Due to Monitoring Period	Var Due to Workload & Allocation Granularity	Var Due to Workload & Monitoring Period	Var Due to Allocation Granularity & Monitoring Period	Var Due to All Factors	Var Due to Error
81.19%	3.11%	1.74%	4.68%	2.86%	1.76%	2.03%	2.62%

Table B.116. Utilization Data — Static Allocation with Work Conservation

	System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
Seed 128	13.21	29.51	20.29	36.58		68.20	84.93	98.72
Seed 129	13.23	29.44	20.35	36.62		68.12	84.98	98.69
Seed 130	13.34	29.47	20.41	36.54		68.30	85.01	98.72
Seed 131	13.32	29.54	20.44	36.67		67.67	84.92	98.73
Seed 132	13.16	29.50	20.35	36.58		66.94	85.01	98.69
Column Sum	66.26	147.46	101.84	182.99	498.55			
Column Mean	13.25	29.49	20.37	36.60	**24.93**	67.85	84.97	98.71
Column Effect	-11.68	4.56	-4.56	11.67				

Table B.117. Utilization Standard Deviations — Static Allocation with Work Conservation

System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
0.074	0.041	0.058	0.049		0.560	0.046	0.016

Table B.118. Utilization Analysis of Variance — Static Allocation with Work Conservation

SSY	SS0	SSA	SST	SSE
13998.37	12427.66	1570.65	1570.70	0.05
		Var Due to Workload 100.00%		Variance Due to Error 0.00%
DOF_Y 20	DOF_0 1	DOF_A 3	DOF_T 19	DOF_E 16
		MSA 523.551		MSE 0.003
		F_{compA} 162847.264		
		F_{TableA} 2.46		
		P-valueA 4.417E-36		

Table B.119. Voice Circuit Queuing Delay Data — Static Allocation with Work Conservation

	System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
Seed 128	19.32	20.07	23.22	23.93		38.71	57.74	71.67
Seed 129	19.36	20.05	23.17	23.89		38.58	58.05	78.12
Seed 130	19.35	20.10	23.13	23.86		38.82	58.24	71.41
Seed 131	19.30	20.10	23.18	23.96		38.32	58.11	80.25
Seed 132	19.34	20.09	23.17	23.92		38.14	59.18	75.16
Column Sum	96.67	100.42	115.87	119.55	432.52			
Column Mean	19.33	20.08	23.17	23.91	**21.63**	38.51	58.26	75.32
Column Effect	-2.29	-1.54	1.55	2.29				

Table B.120. Voice Circuit Queuing Delay Standard Deviations — Static Allocation with Work Conservation

System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
0.022	0.023	0.033	0.039		0.279	0.543	3.900

Table B.121. Voice Circuit Queuing Delay Analysis of Variance — Static Allocation with Work Conservation

SSY	SS0	SSA	SST	SSE
9429.77	9353.49	76.27	76.28	0.01
		Var Due to Workload 99.98%		Variance Due to Error 0.02%
DOF_Y 20	DOF_0 1	DOF_A 3	DOF_T 19	DOF_E 16
		MSA 25.423		MSE 8.924E-04
		F_{compA} 28487.535		
		F_{TableA} 2.46		
		P-valueA 5.031E-30		

Table B.122. Video Circuit Queuing Delay Data — Static Allocation with Work Conservation

	System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
Seed 128	2.55	3.65	5.18	6.91		8.15	13.48	28.68
Seed 129	3.14	3.82	4.31	5.37		8.32	12.52	29.90
Seed 130	3.36	3.51	5.07	5.75		8.05	13.03	28.02
Seed 131	2.84	3.57	5.70	4.99		8.33	12.79	30.09
Seed 132	3.36	4.18	4.92	5.84		8.44	13.31	28.67
Column Sum	15.25	18.73	25.18	28.87	88.02			
Column Mean	3.05	3.75	5.04	5.77	**4.40**	8.26	13.03	29.07
Column Effect	-1.35	-0.65	0.63	1.37				

Table B.123. Video Circuit Queuing Delay Standard Deviations — Static Allocation with Work Conservation

System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
0.353	0.269	0.501	0.720		0.154	0.384	0.884

Table B.124. Video Circuit Queuing Delay Analysis of Variance — Static Allocation with Work Conservation

SSY	SS0	SSA	SST	SSE
413.98	387.41	22.71	26.58	3.87
		Var Due to Workload 85.45%		Variance Due to Error 14.55%
DOF_Y 20	DOF_0 1	DOF_A 3	DOF_T 19	DOF_E 16
		MSA 7.570		MSE 0.242
		F_{compA} 31.329		
		F_{TableA} 2.46		
		P-valueA 6.248E-07		

Table B.125. NIPRNET Circuit Queuing Delay Data — Static Allocation with Work Conservation

	System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
Seed 128	3.02	3.09	4.41	4.61		11.91	19.65	36.42
Seed 129	3.02	3.10	4.41	4.61		11.89	19.57	38.28
Seed 130	3.02	3.10	4.42	4.61		11.93	19.49	33.45
Seed 131	3.00	3.09	4.41	4.62		11.74	19.10	36.54
Seed 132	3.00	3.10	4.37	4.62		11.59	19.95	36.44
Column Sum	15.06	15.48	22.02	23.08	75.64			
Column Mean	3.01	3.10	4.40	4.62	**3.78**	11.81	19.55	36.23
Column Effect	-0.77	-0.69	0.62	0.83				

Table B.126. NIPRNET Circuit Queuing Delay Standard Deviations — Static Allocation with Work Conservation

System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
0.007	0.003	0.021	0.005		0.144	0.304	1.739

Table B.127. NIPRNET Circuit Queuing Delay Analysis of Variance — Static Allocation with Work Conservation

SSY	SS0	SSA	SST	SSE
296.77	286.04	10.73	10.74	0.00
		Var Due to Workload 99.98%		Variance Due to Error 0.02%
DOF_Y 20	DOF_0 1	DOF_A 3	DOF_T 19	DOF_E 16
		MSA 3.578E+00		MSE 1.336E-04
		F_{compA} 26778.795		
		F_{TableA} 2.46		
		P-valueA 8.250E-30		

Table B.128. SIPRNET Circuit Queuing Delay Data — Static Allocation with Work Conservation

	System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
Seed 128	3.14	3.60	4.67	5.90		23.49	42.30	74.74
Seed 129	3.15	3.60	4.74	5.91		23.43	42.08	83.20
Seed 130	3.16	3.61	4.71	5.90		23.46	42.45	81.73
Seed 131	3.15	3.61	4.71	5.93		23.07	42.38	87.86
Seed 132	3.15	3.61	4.72	5.91		22.69	43.72	85.54
Column Sum	15.74	18.04	23.55	29.55	86.88			
Column Mean	3.15	3.61	4.71	5.91	**4.34**	23.23	42.58	82.62
Column Effect	-1.20	-0.74	0.37	1.57				

Table B.129. SIPRNET Circuit Queuing Delay Standard Deviations — Static Allocation with Work Conservation

System Underload	Data Overload	Voice Overload	Voice & Data Overload		70% Offered Load	85% Offered Load	100% Offered Load
0.006	0.004	0.025	0.012		0.348	0.648	4.984

Table B.130. SIPRNET Circuit Queuing Delay Analysis of Variance — Static Allocation with Work Conservation

SSY	SS0	SSA	SST	SSE
400.21	377.41	22.79	22.79	0.00

		Var Due to Workload 99.99%		Variance Due to Error 0.01%
DOF_Y 20	DOF_0 1	DOF_A 3	DOF_T 19	DOF_E 16
		MSA 7.597		MSE 2.066E-04
		F_{compA} 36778.178		
		F_{TableA} 2.46		
		P-valueA 6.521E-31		

Table B.131. Utilization Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	19.97	19.97	19.97	19.50	19.50	19.50	19.97	19.97	19.97
	20.88	20.88	20.88	21.12	21.12	21.12	20.88	20.88	20.88
	17.92	17.92	17.92	17.96	17.96	17.96	17.92	17.92	17.92
	18.96	18.96	18.96	18.60	18.60	18.60	18.96	18.96	18.96
	19.30	19.30	19.30	20.37	20.37	20.37	19.30	19.30	19.30
Data Overload	48.67	48.50	48.78	48.90	48.48	47.83	46.51	45.75	45.81
	49.59	47.79	47.49	50.49	47.58	48.18	47.74	46.52	44.53
	49.09	47.89	47.76	49.19	49.17	46.79	48.17	45.74	45.97
	49.48	47.99	46.75	48.95	48.84	46.94	47.41	46.85	46.11
	50.20	49.04	47.96	49.71	48.52	48.03	46.15	46.84	45.69
Voice Overload	29.36	29.05	28.50	28.73	29.17	28.01	27.57	28.94	27.09
	29.57	27.97	27.79	29.81	30.05	27.79	27.54	28.15	27.41
	29.54	28.61	28.71	29.50	28.38	28.71	27.91	27.48	27.38
	28.89	29.00	28.74	29.70	27.65	28.04	27.62	27.59	27.48
	29.64	28.90	29.16	30.51	28.43	27.61	27.81	27.92	27.18
Voice & Data Overload	47.73	47.02	48.22	47.11	46.09	48.07	45.86	45.61	46.69
	47.50	47.13	47.90	47.22	47.41	46.95	45.64	46.16	46.98
	47.15	47.70	48.50	47.30	47.31	48.23	45.65	46.12	47.03
	47.71	46.91	47.99	47.82	46.92	47.76	46.28	46.07	47.47
	47.05	47.09	47.03	47.35	47.03	47.36	46.53	45.77	46.70
70% Offered Load								74.35	
								74.44	
								73.64	
								73.37	
								73.78	
85% Offered Load								89.31	
								89.27	
								89.22	
								89.26	
								89.27	
100% Offered Load								98.87	
								98.87	
								98.86	
								98.85	
								98.84	

Table B.132. Utilization Means — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean	Row Effect
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)			
System Underload	19.40	19.40	19.40	19.51	19.51	19.51	19.40	19.40	19.40	174.96	19.44	-16.24
Data Overload	49.41	48.24	47.75	49.45	48.52	47.55	47.20	46.34	45.62	430.07	47.79	12.10
Voice Overload	29.40	28.71	28.58	29.65	28.73	28.03	27.69	28.01	27.31	256.12	28.46	-7.22
Voice & Data Overload	47.43	47.17	47.93	47.36	46.95	47.67	45.99	45.95	46.97	423.42	47.05	11.36
Column Sum	145.64	143.52	143.66	145.97	143.71	142.77	140.28	139.71	139.31	1284.57		
Column Mean	36.41	35.88	35.92	36.49	35.93	35.69	35.07	34.93	34.83		**35.68**	
Column Effect	0.73	0.20	0.23	0.81	0.25	0.01	-0.61	-0.76	-0.85			
70% Offered Load								73.92				
85% Offered Load								89.26				
100% Offered Load								98.86				

Table B.133. Utilization Standard Deviations — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	1.109	1.109	1.109	1.282	1.282	1.282	1.109	1.109	1.109
Data Overload	0.569	0.522	0.736	0.664	0.593	0.642	0.843	0.561	0.632
Voice Overload	0.304	0.444	0.502	0.640	0.910	0.417	0.163	0.580	0.168
Voice & Data Overload	0.317	0.307	0.553	0.270	0.522	0.524	0.398	0.245	0.318
70% Offered Load								0.462	
85% Offered Load								0.032	
100% Offered Load								0.013	

Table B.134. Utilization Difference Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	6.76 7.65 4.57 5.65 6.13	6.76 7.65 4.57 5.65 6.13	6.76 7.65 4.57 5.65 6.13	6.28 7.89 4.62 5.28 7.21	6.28 7.89 4.62 5.28 7.21	6.28 7.89 4.62 5.28 7.21	6.76 7.65 4.57 5.65 6.13	6.76 7.65 4.57 5.65 6.13	6.76 7.65 4.57 5.65 6.13
Data Overload	19.16 20.15 19.63 19.94 20.70	18.98 18.36 18.42 18.45 19.54	19.26 18.05 18.29 17.21 18.46	19.38 21.05 19.72 19.41 20.21	18.97 18.15 19.70 19.30 19.02	18.32 18.74 17.32 17.40 18.52	16.99 18.31 18.70 17.87 16.65	16.23 17.09 16.27 17.31 17.34	16.29 15.10 16.50 16.57 16.19
Voice Overload	9.07 9.23 9.13 8.45 9.29	8.76 7.63 8.20 8.56 8.55	8.21 7.45 8.30 8.30 8.81	8.44 9.46 9.09 9.26 10.16	8.88 9.70 7.97 7.21 8.08	7.72 7.45 8.30 7.60 7.26	7.28 7.19 7.50 7.18 7.46	8.64 7.80 7.07 7.15 7.56	6.80 7.07 6.97 7.04 6.83
Voice & Data Overload	11.15 10.88 10.61 11.04 10.47	10.43 10.50 11.16 10.25 10.51	11.64 11.27 11.96 11.32 10.45	10.53 10.60 10.77 11.15 10.77	9.50 10.78 10.78 10.26 10.45	11.48 10.32 11.69 11.09 10.78	9.28 9.01 9.11 9.62 9.95	9.02 9.54 9.59 9.41 9.20	10.11 10.35 10.49 10.80 10.12
70% Offered Load								6.16 6.33 5.34 5.70 6.84	
85% Offered Load								4.38 4.29 4.21 4.35 4.25	
100% Offered Load								0.15 0.17 0.14 0.12 0.14	

Table B.135. Utilization Difference Means — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	6.15	6.15	6.15	6.26	6.26	6.26	6.15	6.15	6.15
Data Overload	19.91	18.75	18.25	19.95	19.03	18.06	17.70	16.85	16.13
Voice Overload	9.03	8.34	8.21	9.28	8.37	7.67	7.32	7.65	6.94
Voice & Data Overload	10.83	10.57	11.33	10.76	10.35	11.07	9.39	9.35	10.38
70% Offered Load								6.07	
85% Offered Load								4.30	
100% Offered Load								0.15	

Table B.136. Utilization Difference Standard Deviations — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	1.156	1.156	1.156	1.342	1.342	1.342	1.156	1.156	1.156
Data Overload	0.575	0.506	0.740	0.697	0.572	0.658	0.864	0.554	0.600
Voice Overload	0.336	0.446	0.489	0.623	0.952	0.395	0.149	0.634	0.125
Voice & Data Overload	0.287	0.347	0.563	0.241	0.525	0.548	0.386	0.238	0.289
70% Offered Load								0.578	
85% Offered Load								0.070	
100% Offered Load								0.019	

Table B.137. Utilization Difference 90% Confidence Intervals — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	5.05 7.25	5.05 7.25	5.05 7.25	4.98 7.54	4.98 7.54	4.98 7.54	5.05 7.25	5.05 7.25	5.05 7.25
Data Overload	19.37 20.46	18.27 19.23	17.55 18.96	19.29 20.62	18.48 19.57	17.43 18.69	16.88 18.53	16.32 17.38	15.56 16.70
Voice Overload	8.71 9.35	7.91 8.76	7.75 8.68	8.69 9.88	7.46 9.27	7.29 8.04	7.18 7.46	7.04 8.25	6.82 7.06
Voice & Data Overload	10.56 11.10	10.24 10.90	10.79 11.87	10.53 10.99	9.85 10.85	10.55 11.60	9.03 9.76	9.12 9.58	10.10 10.65
70% Offered Load								5.52 6.62	
85% Offered Load								4.23 4.36	
100% Offered Load								0.13 0.16	

Table B.138. Utilization Main Effects — DBA-3

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-16.24	12.10	-7.22	11.36
Allocation Granularity	B	0.39	0.36	-0.74	N/A
Monitoring Period	C	0.31	-0.10	-0.20	N/A

Table B.139. Utilization Second Order Interaction Effects — DBA-3

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	-0.42	0.29	0.05	0.08
32 kbps	-0.28	0.37	-0.01	-0.07
64 kbps	0.71	-0.66	-0.05	0.00

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	-0.31	0.59	0.15	-0.43
10 s	0.10	0.02	0.13	-0.25
50 s	0.20	-0.61	-0.28	0.68

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	0.03	0.15	-0.18
10 s	-0.08	-0.01	0.09
50 s	0.05	-0.14	0.09

Table B.140. Utilization Third Order Interaction Effects — DBA-3

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-0.03	0.08	-0.05	-0.15	0.01	0.14	0.18	-0.09	-0.09
Data Overload	0.01	-0.05	0.04	-0.10	0.10	0.00	0.09	-0.05	-0.04
Voice Overload	0.02	-0.13	0.12	0.24	-0.09	-0.15	-0.26	0.23	0.03
Voice & Data Overload	0.01	0.10	-0.11	0.01	-0.01	0.01	-0.01	-0.09	0.10

Table B.141. Utilization Analysis of Variance — DBA-3

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
255996.29	229183.40	26624.30	49.44	8.85	21.37	25.38	2.01	2.10	26812.89	79.44
		Var Due to Workload 99.30%	Var Due to Allocation Granularity 0.18%	Var Due to Monitoring Period 0.03%	Var Due to Workload & Allocation Granularity 0.08%	Var Due to Workload & Monitoring Period 0.09%	Var Due to Allocation Granularity & Monitoring Period 0.01%	Var Due to All Factors 0.01%		Var Due to Error 0.30%
DOF_Y 180	DOF_0 1	DOF_A 3	DOF_B 2	DOF_C 2	DOF_{AB} 6	DOF_{AC} 6	DOF_{BC} 4	DOF_{ABC} 12	DOF_T 179	DOF_E 144
		MSA 8874.766	MSB 24.719	MSC 4.427	MSAB 3.562	MSAC 4.230	MSBC 0.503	MSABC 0.175		MSE 0.552
		F_{compA} 16087.767	F_{compB} 44.809	F_{compC} 8.024	F_{compAB} 6.457	F_{compAC} 7.668	F_{compBC} 0.912	$F_{compABC}$ 0.317		
		F_{TableA} 2.20	F_{TableB} 2.41	F_{TableC} 2.41	$F_{TableAB}$ 1.90	$F_{TableAC}$ 1.90	$F_{TableBC}$ 2.06	$F_{TableABC}$ 1.68		
		P-valueA 1.178E-181	P-valueB 7.407E-16	P-valueC 4.965E-04	P-valueAB 4.768E-06	P-valueAC 3.695E-07	P-valueBC 0.459	P-valueABC 0.985		

Table B.142. Voice Circuit Queuing Delay Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	33.28	31.15	30.52	28.42	26.30	25.60	25.76	23.80	23.07
	32.83	31.05	29.95	28.20	26.23	24.74	25.92	23.89	23.17
	33.87	31.65	30.46	28.65	26.60	25.50	26.15	24.01	23.00
	33.29	31.48	30.60	28.79	26.82	25.63	26.13	24.14	23.15
	33.31	31.50	29.93	28.61	26.40	25.31	25.84	23.92	23.11
Data Overload	47.19	44.78	43.13	46.80	44.12	44.52	40.00	38.19	36.89
	46.73	44.84	43.61	46.43	45.09	44.61	39.41	37.72	37.80
	46.43	44.49	44.58	46.74	43.62	43.48	39.18	37.99	38.11
	46.41	44.95	45.46	47.03	43.97	44.29	39.22	37.65	37.16
	46.53	44.18	44.44	45.98	43.74	43.30	40.14	37.62	37.19
Voice Overload	33.06	31.38	31.50	32.25	32.25	31.65	29.28	28.43	29.46
	32.48	31.61	30.98	31.56	31.56	30.70	29.31	28.92	29.28
	32.56	31.31	31.10	31.79	31.79	30.20	29.29	28.90	29.16
	32.73	31.48	30.96	31.79	31.79	30.59	29.30	28.90	29.07
	32.43	31.53	30.07	31.63	31.63	30.73	29.31	28.93	29.13
Voice & Data Overload	51.85	52.12	59.78	51.37	50.91	64.22	43.23	43.96	50.54
	51.84	50.65	62.23	50.46	51.65	64.30	42.56	43.92	51.92
	50.84	50.88	61.79	50.63	50.79	61.24	43.60	43.66	52.95
	51.24	50.68	60.93	51.04	51.22	58.79	43.45	44.38	51.18
	51.36	50.84	59.70	50.61	51.31	59.47	44.23	43.21	51.22
70% Offered Load								144.56	
								144.32	
								143.59	
								143.27	
								144.60	
85% Offered Load								388.53	
								389.00	
								379.96	
								376.84	
								387.14	
100% Offered Load								195.79	
								185.89	
								190.99	
								181.88	
								169.43	

Table B.143. Voice Circuit Queuing Delay Means — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean	Row Effect
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)			
System Underload	33.32	31.36	30.29	28.53	26.47	25.36	25.96	23.95	23.10	248.34	27.59	-10.63
Data Overload	46.66	44.65	44.24	46.60	44.11	44.04	39.59	37.83	37.43	385.15	42.79	4.57
Voice Overload	32.65	31.46	30.92	31.80	31.80	30.77	29.30	28.82	29.22	276.75	30.75	-7.47
Voice & Data Overload	51.43	51.03	60.88	50.82	51.18	61.60	43.41	43.82	51.56	465.74	51.75	13.53
Column Sum	164.05	158.51	166.34	157.75	153.56	161.77	138.26	134.43	141.31	1375.98		
Column Mean	41.01	39.63	41.59	39.44	38.39	40.44	34.57	33.61	35.33		**38.22**	
Column Effect	2.79	1.41	3.36	1.22	0.17	2.22	-3.66	-4.61	-2.89			
70% Offered Load								144.07				
85% Offered Load								384.30				
100% Offered Load								184.79				

Table B.144. Voice Circuit Queuing Delay Standard Deviations — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.371	0.254	0.325	0.229	0.240	0.369	0.173	0.129	0.069
Data Overload	0.323	0.312	0.906	0.405	0.584	0.609	0.451	0.244	0.504
Voice Overload	0.258	0.118	0.522	0.270	0.270	0.534	0.014	0.214	0.153
Voice & Data Overload	0.429	0.613	1.147	0.373	0.341	2.584	0.603	0.430	0.916
70% Offered Load								0.603	
85% Offered Load								5.537	
100% Offered Load								10.063	

Table B.145. Voice Circuit Queuing Delay Difference Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	13.96	11.83	11.20	9.10	6.98	6.29	6.44	4.48	3.75
	13.47	11.69	10.59	8.84	6.88	5.38	6.56	4.54	3.82
	14.52	12.30	11.11	9.30	7.25	6.15	6.80	4.66	3.65
	13.98	12.17	11.30	9.48	7.52	6.33	6.82	4.84	3.84
	13.98	12.16	10.59	9.27	7.06	5.98	6.50	4.58	3.77
Data Overload	27.12	24.71	23.06	26.73	24.05	24.46	19.93	18.12	16.83
	26.68	24.79	23.56	26.37	25.04	24.56	19.35	17.67	17.75
	26.32	24.39	24.48	26.64	23.51	23.38	19.07	17.88	18.00
	26.31	24.85	25.36	26.93	23.86	24.18	19.11	17.55	17.05
	26.44	24.09	24.35	25.89	23.65	23.21	20.05	17.53	17.10
Voice Overload	9.84	8.16	8.28	9.03	9.03	8.43	6.06	5.21	6.24
	9.30	8.44	7.81	8.39	8.39	7.52	6.14	5.75	6.10
	9.43	8.18	7.97	8.66	8.66	7.07	6.16	5.77	6.03
	9.55	8.30	7.79	8.62	8.62	7.41	6.12	5.72	5.90
	9.26	8.35	6.90	8.45	8.45	7.55	6.14	5.75	5.96
Voice & Data Overload	27.92	28.19	35.85	27.44	26.98	40.29	19.30	20.03	26.62
	27.96	26.76	38.34	26.58	27.76	40.41	18.68	20.04	28.04
	26.98	27.02	37.93	26.77	26.93	37.38	19.74	19.80	29.09
	27.28	26.72	36.97	27.08	27.26	34.83	19.49	20.42	27.22
	27.43	26.92	35.77	26.68	27.39	35.55	20.30	19.29	27.30
70% Offered Load								105.85	
								105.74	
								104.77	
								104.95	
								106.46	
85% Offered Load								330.79	
								330.96	
								321.72	
								318.73	
								327.97	
100% Offered Load								124.12	
								107.77	
								119.58	
								101.62	
								94.26	

Table B.146. Voice Circuit Queuing Delay Difference Means — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	13.98	12.03	10.96	9.20	7.14	6.02	6.63	4.62	3.77
Data Overload	26.57	24.57	24.16	26.51	24.02	23.96	19.51	17.75	17.35
Voice Overload	9.48	8.29	7.75	8.63	8.63	7.60	6.12	5.64	6.05
Voice & Data Overload	27.51	27.12	36.97	26.91	27.26	37.69	19.50	19.91	27.65
70% Offered Load								105.56	
85% Offered Load								326.03	
100% Offered Load								109.47	

Table B.147. Voice Circuit Queuing Delay Difference Standard Deviations — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.373	0.257	0.342	0.242	0.253	0.387	0.175	0.138	0.074
Data Overload	0.340	0.319	0.886	0.400	0.604	0.624	0.459	0.249	0.503
Voice Overload	0.236	0.115	0.513	0.252	0.252	0.503	0.041	0.241	0.133
Voice & Data Overload	0.421	0.609	1.171	0.352	0.337	2.602	0.595	0.416	0.948
70% Offered Load								0.692	
85% Offered Load								5.534	
100% Offered Load								12.374	

Table B.148. Voice Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	13.63 14.34	11.78 12.28	10.63 11.28	8.97 9.43	6.90 7.38	5.65 6.39	6.46 6.79	4.49 4.75	3.70 3.84
Data Overload	26.25 26.90	24.26 24.87	23.32 25.01	26.13 26.89	23.45 24.60	23.36 24.55	19.07 19.94	17.51 17.99	16.87 17.83
Voice Overload	9.25 9.70	8.18 8.40	7.26 8.24	8.39 8.87	8.39 8.87	7.12 8.08	6.08 6.16	5.41 5.87	5.92 6.17
Voice & Data Overload	27.11 27.92	26.54 27.70	35.86 38.09	26.58 27.25	26.94 27.59	35.21 40.17	18.94 20.07	19.52 20.31	26.75 28.56
70% Offered Load								104.90 106.22	
85% Offered Load								320.76 331.31	
100% Offered Load								97.67 121.27	

Table B.149. Voice Circuit Queuing Delay Main Effects — DBA-3

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-10.63	4.57	-7.47	13.53
Allocation Granularity	B	2.52	1.20	-3.72	N/A
Monitoring Period	C	0.12	-1.01	0.90	N/A

Table B.150. Voice Circuit Queuing Delay Second Order Interaction Effects — DBA-3

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	1.54	-0.13	-1.59	0.18
32 kbps	-2.01	0.92	-0.49	1.58
64 kbps	0.47	-0.79	2.08	-1.76

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	1.56	1.37	0.38	-3.31
10 s	0.68	0.42	0.96	-2.06
50 s	-2.24	-1.79	-1.34	5.37

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	0.15	-0.10	-0.05
10 s	-0.10	-0.02	0.12
50 s	-0.05	0.12	-0.07

Table B.151. Voice Circuit Queuing Delay Third Order Interaction Effects — DBA-3

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-0.17	0.14	0.03	0.17	0.04	-0.21	0.00	-0.17	0.18
Data Overload	-0.17	0.16	0.00	0.30	-0.19	-0.11	-0.13	0.03	0.10
Voice Overload	0.32	-0.06	-0.26	-0.05	0.42	-0.37	-0.26	-0.36	0.62
Voice & Data Overload	0.02	-0.24	0.22	-0.41	-0.27	0.68	0.39	0.51	-0.90

Table B.152. Voice Circuit Queuing Delay Analysis of Variance — DBA-3

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
282432.10	262962.12	16771.04	1298.65	110.75	312.92	901.09	1.69	17.56	19469.98	56.29
		Var Due to Workload 86.14%	Var Due to Allocation Granularity 6.67%	Var Due to Monitoring Period 0.57%	Var Due to Workload & Allocation Granularity 1.61%	Var Due to Workload & Monitoring Period 4.63%	Var Due to Allocation Granularity & Monitoring Period 0.01%	Var Due to All Factors 0.09%		Var Due to Error 0.29%
DOF_Y 180	DOF_0 1	DOF_A 3	DOF_B 2	DOF_C 2	DOF_{AB} 6	DOF_{AC} 6	DOF_{BC} 4	DOF_{ABC} 12	DOF_T 179	DOF_E 144
		MSA 5590.347	MSB 649.325	MSC 55.375	MSAB 52.153	MSAC 150.181	MSBC 0.422	MSABC 1.464		MSE 0.391
		F_{compA} 14300.889	F_{compB} 1661.065	F_{compC} 141.656	F_{compAB} 133.414	F_{compAC} 384.184	F_{compBC} 1.078	$F_{compABC}$ 3.744		
		F_{TableA} 2.20	F_{TableB} 2.41	F_{TableC} 2.41	$F_{TableAB}$ 1.90	$F_{TableAC}$ 1.90	$F_{TableBC}$ 2.06	$F_{TableABC}$ 1.68		
		P-valueA 5.509E-178	P-valueB 3.414E-100	P-valueC 9.738E-35	P-valueAB 3.007E-56	P-valueAC 5.933E-86	P-valueBC 3.695E-01	P-valueABC 6.124E-05		

Table B.153. Video Circuit Queuing Delay Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	3.05	3.06	3.31	3.26	2.62	2.54	3.40	3.31	3.33
	3.45	3.24	3.27	3.45	3.12	3.14	3.63	3.03	3.06
	3.31	2.52	3.00	3.40	2.92	3.51	3.30	3.31	3.30
	2.95	2.95	3.10	2.85	3.31	3.04	3.22	3.21	3.22
	3.13	3.50	3.52	3.72	3.38	3.36	3.58	3.55	3.58
Data Overload	3.80	3.46	3.84	3.91	3.35	4.04	3.91	3.69	4.15
	3.62	3.68	3.55	3.93	3.97	3.57	3.73	3.91	3.70
	4.05	3.99	3.80	3.65	4.21	3.98	4.29	3.91	3.99
	3.69	3.68	3.64	3.99	4.03	3.73	3.26	3.81	4.11
	4.43	3.70	3.66	3.73	3.69	3.51	4.19	3.30	3.29
Voice Overload	7.40	6.34	6.70	6.57	6.09	6.23	5.85	5.90	6.39
	7.41	6.37	6.05	5.95	6.14	5.74	5.67	6.05	5.56
	7.52	6.49	6.56	6.02	5.92	6.00	5.94	6.26	5.47
	6.15	6.51	6.70	6.95	6.52	6.12	5.86	6.09	5.95
	7.50	6.77	6.15	7.23	5.82	5.63	6.24	6.25	6.30
Voice & Data Overload	10.64	10.75	9.97	9.86	9.34	9.80	10.19	9.44	9.86
	10.75	9.85	10.39	10.25	11.75	9.87	9.96	8.98	10.13
	11.32	10.50	9.76	10.88	10.21	8.47	10.27	9.59	9.83
	9.84	9.16	11.36	10.71	9.84	9.62	10.86	9.25	10.54
	10.91	9.58	10.46	9.85	9.43	11.95	10.95	11.08	9.20
70% Offered Load								17.98	
								17.82	
								18.11	
								18.19	
								17.99	
85% Offered Load								37.13	
								37.89	
								38.16	
								38.21	
								36.89	
100% Offered Load								39.36	
								38.21	
								40.27	
								39.02	
								38.89	

Table B.154. Video Circuit Queuing Delay Means — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)		
System Underload	3.18	3.05	3.24	3.34	3.07	3.12	3.43	3.28	3.30	29.00	3.22
Data Overload	3.92	3.70	3.70	3.84	3.85	3.77	3.88	3.72	3.85	34.22	3.80
Voice Overload	7.20	6.50	6.43	6.54	6.10	5.94	5.91	6.11	5.94	56.67	6.30
Voice & Data Overload	10.69	9.97	10.39	10.31	10.11	9.94	10.45	9.67	9.91	91.44	10.16
Column Sum	24.99	23.22	23.75	24.03	23.13	22.77	23.66	22.78	22.99	211.34	
Column Mean	6.25	5.81	5.94	6.01	5.78	5.69	5.92	5.70	5.75		**5.87**
Column Effect	0.38	-0.06	0.07	0.14	-0.09	-0.18	0.04	-0.17	-0.12		
70% Offered Load								18.02			
85% Offered Load								37.66			
100% Offered Load								39.15			

Table B.155. Video Circuit Queuing Delay Standard Deviations — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.203	0.364	0.199	0.320	0.309	0.371	0.178	0.187	0.190
Data Overload	0.329	0.190	0.119	0.144	0.336	0.240	0.412	0.253	0.359
Voice Overload	0.587	0.170	0.310	0.560	0.270	0.254	0.207	0.149	0.418
Voice & Data Overload	0.543	0.654	0.617	0.475	0.980	1.256	0.435	0.822	0.488
70% Offered Load								0.140	
85% Offered Load								0.609	
100% Offered Load								0.753	

Table B.156. Video Circuit Queuing Delay Difference Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.50	0.51	0.76	0.72	0.08	0.00	0.85	0.76	0.78
	0.31	0.10	0.13	0.31	-0.02	0.00	0.49	-0.11	-0.08
	-0.04	-0.84	-0.36	0.04	-0.44	0.15	-0.06	-0.05	-0.06
	0.11	0.11	0.26	0.01	0.47	0.21	0.38	0.37	0.38
	-0.23	0.14	0.16	0.36	0.02	0.00	0.22	0.19	0.22
Data Overload	0.16	-0.19	0.19	0.26	-0.30	0.40	0.26	0.04	0.50
	-0.20	-0.14	-0.27	0.11	0.15	-0.25	-0.09	0.09	-0.12
	0.53	0.48	0.28	0.14	0.69	0.47	0.78	0.40	0.48
	0.12	0.11	0.06	0.42	0.46	0.16	-0.32	0.24	0.54
	0.25	-0.48	-0.52	-0.45	-0.49	-0.68	0.01	-0.88	-0.89
Voice Overload	2.22	1.16	1.51	1.39	0.91	1.05	0.67	0.72	1.20
	3.10	2.06	1.74	1.64	1.83	1.43	1.36	1.74	1.26
	2.45	1.43	1.49	0.96	0.85	0.94	0.87	1.20	0.40
	0.45	0.81	1.00	1.26	0.83	0.42	0.16	0.39	0.26
	2.57	1.85	1.23	2.30	0.90	0.70	1.31	1.32	1.38
Voice & Data Overload	3.73	3.84	3.06	2.95	2.43	2.89	3.28	2.53	2.95
	5.38	4.48	5.01	4.88	6.38	4.49	4.59	3.61	4.76
	5.57	4.75	4.01	5.13	4.46	2.71	4.52	3.84	4.07
	4.85	4.18	6.37	5.72	4.85	4.64	5.88	4.26	5.55
	5.07	3.74	4.62	4.01	3.59	6.10	5.11	5.24	3.36
70% Offered Load								9.82	
								9.50	
								10.06	
								9.86	
								9.55	
85% Offered Load								23.65	
								25.36	
								25.13	
								25.42	
								23.58	
100% Offered Load								10.68	
								8.31	
								12.24	
								8.93	
								10.21	

Table B.157. Video Circuit Queuing Delay Difference Means — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.13	0.00	0.19	0.29	0.02	0.07	0.38	0.23	0.25
Data Overload	0.17	-0.04	-0.05	0.10	0.10	0.02	0.13	-0.02	0.10
Voice Overload	2.16	1.46	1.40	1.51	1.06	0.91	0.88	1.07	0.90
Voice & Data Overload	4.92	4.20	4.61	4.54	4.34	4.17	4.67	3.89	4.14
70% Offered Load								9.76	
85% Offered Load								24.63	
100% Offered Load								10.08	

Table B.158. Video Circuit Queuing Delay Difference Standard Deviations — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.287	0.501	0.399	0.289	0.324	0.099	0.336	0.351	0.357
Data Overload	0.262	0.358	0.336	0.331	0.497	0.479	0.420	0.500	0.619
Voice Overload	1.008	0.507	0.287	0.508	0.431	0.379	0.495	0.529	0.526
Voice & Data Overload	0.718	0.425	1.230	1.079	1.470	1.398	0.950	0.987	1.049
70% Offered Load								0.232	
85% Offered Load								0.932	
100% Offered Load								1.543	

Table B.159. Video Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-0.14 0.40	-0.47 0.48	-0.19 0.57	0.01 0.56	-0.29 0.33	-0.02 0.16	0.06 0.70	-0.10 0.57	-0.09 0.59
Data Overload	-0.08 0.42	-0.39 0.30	-0.37 0.27	-0.22 0.41	-0.37 0.58	-0.44 0.48	-0.27 0.53	-0.50 0.45	-0.49 0.69
Voice Overload	1.20 3.12	0.98 1.95	1.12 1.67	1.02 1.99	0.65 1.47	0.55 1.27	0.40 1.35	0.57 1.58	0.40 1.40
Voice & Data Overload	4.24 5.61	3.79 4.60	3.44 5.79	3.51 5.57	2.94 5.74	2.83 5.50	3.77 5.58	2.95 4.84	3.14 5.14
70% Offered Load								9.54 9.98	
85% Offered Load								23.74 25.52	
100% Offered Load								8.60 11.55	

Table B.160. Video Circuit Queuing Delay Main Effects — DBA-3

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-2.65	-2.07	0.43	4.29
Allocation Granularity	B	0.13	-0.04	-0.08	N/A
Monitoring Period	C	0.19	-0.11	-0.08	N/A

Table B.161. Video Circuit Queuing Delay Second Order Interaction Effects — DBA-3

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	-0.19	-0.16	0.28	0.06
32 kbps	0.00	0.06	-0.06	0.00
64 kbps	0.20	0.10	-0.23	-0.07

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	-0.10	-0.11	0.07	0.14
10 s	0.02	0.06	0.05	-0.13
50 s	0.07	0.05	-0.12	0.00

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	0.06	-0.01	-0.06
10 s	-0.08	0.06	0.02
50 s	0.02	-0.06	0.04

Table B.162. Video Circuit Queuing Delay Third Order Interaction Effects — DBA-3

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-0.13	0.06	0.07	0.08	-0.08	0.01	0.06	0.02	-0.07
Data Overload	0.01	0.06	-0.06	-0.05	0.01	0.04	0.04	-0.07	0.03
Voice Overload	0.17	-0.07	-0.10	0.10	-0.10	0.00	-0.27	0.17	0.10
Voice & Data Overload	-0.04	-0.06	0.10	-0.13	0.17	-0.04	0.17	-0.12	-0.06

Table B.163. Video Circuit Queuing Delay Analysis of Variance — DBA-3

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
7589.52	6203.13	1344.33	1.49	3.16	3.86	1.36	0.48	1.75	1386.40	29.97
		Var Due to Workload 96.97%	Var Due to Allocation Granularity 0.11%	Var Due to Monitoring Period 0.23%	Var Due to Workload & Allocation Granularity 0.28%	Var Due to Workload & Monitoring Period 0.10%	Var Due to Allocation Granularity & Monitoring Period 0.03%	Var Due to All Factors 0.13%		Var Due to Error 2.16%
DOF_Y 180	DOF_0 1	DOF_A 3	DOF_B 2	DOF_C 2	DOF_{AB} 6	DOF_{AC} 6	DOF_{BC} 4	DOF_{ABC} 12	DOF_T 179	DOF_E 144
		MSA 448.109	MSB 0.746	MSC 1.581	MSAB 0.643	MSAC 0.226	MSBC 0.119	MSABC 0.146		MSE 0.208
		F_{compA} 2152.811	F_{compB} 3.585	F_{compC} 7.597	F_{compAB} 3.087	F_{compAC} 1.087	F_{compBC} 0.573	$F_{compABC}$ 0.701		
		F_{TableA} 2.20	F_{TableB} 2.41	F_{TableC} 2.41	$F_{TableAB}$ 1.90	$F_{TableAC}$ 1.90	$F_{TableBC}$ 2.06	$F_{TableABC}$ 1.68		
		P-valueA 2.302E-119	P-valueB 3.024E-02	P-valueC 7.303E-04	P-valueAB 7.130E-03	P-valueAC 0.373	P-valueBC 0.682	P-valueABC 0.749		

Table B.164. NIPRNET Circuit Queuing Delay Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	3.38	3.37	3.37	3.31	3.29	3.29	3.29	3.27	3.26
	3.43	3.41	3.40	3.38	3.36	3.35	3.34	3.32	3.31
	3.30	3.28	3.27	3.25	3.23	3.21	3.21	3.18	3.16
	3.34	3.33	3.32	3.27	3.25	3.24	3.26	3.24	3.22
	3.34	3.34	3.31	3.35	3.33	3.31	3.26	3.24	3.23
Data Overload	4.90	4.89	4.86	4.89	4.88	4.94	4.37	4.32	4.33
	4.95	4.86	4.85	4.93	4.88	4.87	4.41	4.38	4.32
	4.91	4.85	4.88	4.94	4.82	4.80	4.44	4.34	4.46
	4.92	4.88	4.85	4.88	4.87	4.82	4.38	4.38	4.34
	4.93	4.87	4.87	4.91	4.89	4.86	4.38	4.38	4.35
Voice Overload	12.41	12.02	11.30	12.20	11.71	11.14	9.63	9.37	9.06
	12.32	11.80	11.25	12.17	11.75	10.90	9.55	9.52	8.92
	12.33	11.83	11.19	12.16	11.76	10.91	9.55	9.30	9.00
	12.30	11.97	11.32	12.06	11.72	10.98	9.70	9.43	8.92
	12.13	12.03	11.19	12.16	11.68	10.75	9.62	9.34	8.97
Voice & Data Overload	11.61	10.92	10.22	11.36	10.64	10.25	9.19	8.89	8.46
	11.44	10.86	10.27	11.34	10.94	10.08	9.09	8.78	8.62
	11.41	10.96	10.23	11.35	10.92	10.32	9.16	9.06	8.69
	11.26	10.87	10.11	11.47	10.98	9.91	9.32	8.92	8.68
	11.42	10.79	9.98	11.28	10.75	9.97	9.49	8.80	8.53
70% Offered Load								23.97	
								23.64	
								23.10	
								23.10	
								23.07	
85% Offered Load								62.42	
								63.88	
								64.40	
								63.58	
								62.46	
100% Offered Load								58.58	
								56.41	
								63.55	
								56.62	
								61.09	

Table B.165. NIPRNET Circuit Queuing Delay Means — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)		
System Underload	3.36	3.34	3.34	3.31	3.07	3.28	3.27	3.25	3.24	29.46	3.27
Data Overload	4.92	4.87	4.86	4.91	4.87	4.86	4.40	4.36	4.36	42.41	4.71
Voice Overload	12.30	11.93	11.25	12.15	11.72	10.94	9.61	9.39	8.97	98.27	10.92
Voice & Data Overload	11.43	10.88	10.16	11.36	10.85	10.11	9.25	8.89	8.60	91.51	10.17
Column Sum	32.01	31.02	29.61	31.73	30.51	29.18	26.53	25.89	25.17	261.65	
Column Mean	8.00	7.76	7.40	7.93	7.63	7.30	6.63	6.47	6.29		**7.27**
Column Effect	0.73	0.49	0.13	0.66	0.36	0.03	-0.64	-0.80	-0.98		
70% Offered Load								23.37			
85% Offered Load								63.35			
100% Offered Load								59.25			

Table B.166. NIPRNET Circuit Queuing Delay Standard Deviations — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.047	0.049	0.049	0.055	0.055	0.054	0.050	0.050	0.054
Data Overload	0.019	0.014	0.015	0.026	0.027	0.054	0.027	0.028	0.057
Voice Overload	0.102	0.108	0.061	0.054	0.031	0.145	0.065	0.087	0.059
Voice & Data Overload	0.126	0.066	0.119	0.070	0.144	0.176	0.155	0.110	0.096
70% Offered Load								0.407	
85% Offered Load								0.879	
100% Offered Load								3.053	

Table B.167. NIPRNET Circuit Queuing Delay Difference Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.36 0.41 0.28 0.34 0.34	0.35 0.40 0.26 0.33 0.33	0.35 0.38 0.26 0.32 0.31	0.29 0.37 0.23 0.26 0.34	0.28 0.35 0.21 0.25 0.33	0.27 0.33 0.19 0.24 0.31	0.28 0.33 0.19 0.26 0.25	0.25 0.30 0.16 0.23 0.24	0.25 0.30 0.15 0.22 0.22
Data Overload	1.81 1.85 1.81 1.83 1.83	1.79 1.76 1.76 1.78 1.77	1.77 1.75 1.78 1.75 1.77	1.80 1.83 1.85 1.79 1.81	1.79 1.78 1.73 1.77 1.80	1.85 1.77 1.70 1.73 1.76	1.28 1.32 1.34 1.29 1.28	1.22 1.28 1.24 1.29 1.28	1.24 1.23 1.37 1.25 1.26
Voice Overload	8.00 7.90 7.91 7.89 7.77	7.61 7.39 7.41 7.55 7.67	6.89 6.84 6.77 6.91 6.82	7.79 7.76 7.74 7.65 7.79	7.30 7.34 7.34 7.31 7.31	6.73 6.49 6.49 6.57 6.38	5.22 5.14 5.13 5.29 5.25	4.96 5.11 4.88 5.02 4.97	4.65 4.50 4.58 4.51 4.60
Voice & Data Overload	7.00 6.83 6.79 6.64 6.80	6.31 6.25 6.35 6.24 6.17	5.60 5.66 5.62 5.49 5.36	6.74 6.73 6.74 6.85 6.67	6.03 6.33 6.31 6.36 6.13	5.64 5.47 5.71 5.28 5.36	4.57 4.48 4.55 4.69 4.87	4.28 4.17 4.45 4.29 4.18	3.85 4.01 4.07 4.06 3.92
70% Offered Load								12.05 11.75 11.17 11.36 11.48	
85% Offered Load								42.77 44.31 44.91 44.47 42.52	
100% Offered Load								22.16 18.13 30.10 20.08 24.64	

Table B.168. NIPRNET Circuit Queuing Delay Difference Means — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.35	0.33	0.32	0.30	0.28	0.27	0.26	0.24	0.23
Data Overload	1.83	1.77	1.77	1.82	1.77	1.76	1.30	1.26	1.27
Voice Overload	7.89	7.53	6.85	7.75	7.32	6.53	5.21	4.99	4.57
Voice & Data Overload	6.81	6.26	5.54	6.74	6.23	5.49	4.63	4.27	3.98
70% Offered Load								11.56	
85% Offered Load								43.80	
100% Offered Load								23.02	

Table B.169. NIPRNET Circuit Queuing Delay Difference Standard Deviations — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.046	0.049	0.048	0.056	0.056	0.055	0.050	0.051	0.054
Data Overload	0.017	0.016	0.014	0.024	0.027	0.054	0.026	0.027	0.056
Voice Overload	0.085	0.122	0.055	0.060	0.017	0.132	0.070	0.083	0.063
Voice & Data Overload	0.129	0.068	0.122	0.066	0.143	0.179	0.152	0.110	0.095
70% Offered Load								0.345	
85% Offered Load								1.077	
100% Offered Load								4.638	

Table B.170. NIPRNET Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.30 0.39	0.29 0.38	0.28 0.37	0.24 0.35	0.23 0.33	0.22 0.32	0.21 0.31	0.19 0.28	0.17 0.28
Data Overload	1.81 1.84	1.76 1.79	1.75 1.78	1.79 1.84	1.75 1.80	1.71 1.81	1.28 1.33	1.24 1.29	1.21 1.32
Voice Overload	7.81 7.98	7.41 7.64	6.79 6.90	7.69 7.80	7.30 7.33	6.41 6.66	5.14 5.27	4.91 5.07	4.51 4.63
Voice & Data Overload	6.69 6.94	6.20 6.33	5.43 5.66	6.68 6.81	6.09 6.37	5.32 5.66	4.49 4.78	4.17 4.38	3.89 4.07
70% Offered Load								11.23 11.89	
85% Offered Load								42.77 44.82	
100% Offered Load								18.60 27.44	

Table B.171. NIPRNET Circuit Queuing Delay Main Effects — DBA-3

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-4.00	-2.56	3.65	2.90
Allocation Granularity	B	0.45	0.35	-0.80	N/A
Monitoring Period	C	0.25	0.02	-0.27	N/A

Table B.172. NIPRNET Circuit Queuing Delay Second Order Interaction Effects — DBA-3

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	-0.38	-0.28	0.46	0.20
32 kbps	-0.40	-0.18	0.33	0.25
64 kbps	0.78	0.46	-0.79	-0.45

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	-0.21	-0.22	0.18	0.26
10 s	-0.07	-0.03	0.08	0.02
50 s	0.28	0.25	-0.26	-0.28

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	0.03	0.06	-0.09
10 s	0.02	-0.01	-0.01
50 s	-0.05	-0.05	0.10

Table B.173. NIPRNET Circuit Queuing Delay Third Order Interaction Effects — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-0.06	0.03	0.02	-0.01	-0.09	0.10	0.07	0.06	-0.12
Data Overload	-0.02	-0.02	0.04	-0.06	0.01	0.05	0.08	0.01	-0.09
Voice Overload	0.01	-0.01	0.00	0.05	0.03	-0.08	-0.06	-0.02	0.08
Voice & Data Overload	0.07	0.00	-0.07	0.02	0.05	-0.07	-0.09	-0.05	0.13

Table B.174. NIPRNET Circuit Queuing Delay Analysis of Variance — DBA-3

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
11619.40	9508.27	1990.46	58.24	8.32	37.48	7.41	0.54	0.67	2111.12	8.00
		Var Due to Workload 94.28%	Var Due to Allocation Granularity 2.76%	Var Due to Monitoring Period 0.39%	Var Due to Workload & Allocation Granularity 1.78%	Var Due to Workload & Monitoring Period 0.35%	Var Due to Allocation Granularity & Monitoring Period 0.03%	Var Due to All Factors 0.03%		Var Due to Error 0.38%
DOF_Y 180	DOF_0 1	DOF_A 3	DOF_B 2	DOF_C 2	DOF_{AB} 6	DOF_{AC} 6	DOF_{BC} 4	DOF_{ABC} 12	DOF_T 179	DOF_E 144
		MSA 663.487	MSB 29.122	MSC 4.158	MSAB 6.246	MSAC 1.235	MSBC 0.135	MSABC 0.056		MSE 0.056
		F_{compA} 11942.594	F_{compB} 524.189	F_{compC} 74.851	F_{compAB} 112.430	F_{compAC} 22.237	F_{compBC} 2.422	$F_{compABC}$ 1.009		
		F_{TableA} 2.20	F_{TableB} 2.41	F_{TableC} 2.41	$F_{TableAB}$ 1.90	$F_{TableAC}$ 1.90	$F_{TableBC}$ 2.06	$F_{TableABC}$ 1.68		
		P-valueA 2.266E-172	P-valueB 7.949E-67	P-valueC 5.162E-23	P-valueAB 8.466E-52	P-valueAC 2.017E-18	P-valueBC 5.097E-02	P-valueABC 0.444		

Table B.175. SIPRNET Circuit Queuing Delay Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	3.54	3.52	3.50	3.45	3.41	3.40	3.42	3.40	3.38
	3.58	3.55	3.52	3.53	3.49	3.47	3.47	3.43	3.42
	3.45	3.42	3.39	3.38	3.33	3.32	3.33	3.30	3.28
	3.49	3.46	3.44	3.43	3.40	3.36	3.38	3.35	3.34
	3.51	3.49	3.44	3.50	3.46	3.43	3.39	3.37	3.35
Data Overload	7.40	7.30	7.15	7.33	7.29	7.27	6.05	5.91	5.83
	7.40	7.30	7.12	7.34	7.35	7.15	6.06	5.99	5.88
	7.39	7.29	7.23	7.43	7.11	7.05	6.08	5.97	6.05
	7.38	7.33	7.16	7.39	7.21	7.13	6.04	6.01	5.85
	7.37	7.27	7.19	7.41	7.36	7.08	6.08	5.99	5.87
Voice Overload	16.14	14.69	13.58	14.71	14.58	13.30	11.68	10.94	10.51
	15.79	14.38	13.12	14.70	14.25	12.85	11.35	11.26	10.51
	15.77	14.50	13.38	15.50	14.37	12.75	11.54	11.21	10.45
	15.60	14.92	13.37	14.99	14.09	13.28	11.53	11.01	10.52
	15.74	14.68	13.16	15.15	13.77	12.85	11.65	10.93	10.45
Voice & Data Overload	21.92	20.76	19.15	21.84	20.34	19.43	16.77	16.27	15.44
	21.67	20.55	19.17	21.65	20.55	19.16	16.58	15.94	15.61
	21.57	20.74	19.19	21.34	20.78	19.48	16.81	16.56	15.92
	21.47	20.64	19.16	21.89	20.83	18.55	16.95	16.31	15.56
	21.55	20.59	19.07	21.41	20.37	19.06	17.12	15.97	15.66
70% Offered Load								37.32	
								37.22	
								36.37	
								36.31	
								36.84	
85% Offered Load								85.93	
								86.71	
								86.14	
								85.94	
								85.62	
100% Offered Load								110.44	
								106.30	
								111.50	
								104.94	
								101.26	

Table B.176. SIPRNET Circuit Queuing Delay Means — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps			Row Sum	Row Mean	Row Effect
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)			
System Underload	3.51	3.49	3.46	3.46	3.42	3.40	3.40	3.37	3.35	30.86	3.43	-7.21
Data Overload	7.39	7.30	7.17	7.38	7.26	7.14	6.06	5.97	5.90	61.57	6.84	-3.80
Voice Overload	15.81	14.63	13.32	15.01	14.21	13.01	11.55	11.07	10.49	119.10	13.23	2.59
Voice & Data Overload	21.63	20.66	19.15	21.63	20.58	19.14	16.85	16.21	15.64	171.47	19.05	8.41
Column Sum	48.34	46.07	43.10	47.47	45.47	42.68	37.86	36.62	35.37	382.99		
Column Mean	12.09	11.52	10.77	11.87	11.37	10.67	9.46	9.16	8.84		**10.64**	
Column Effect	1.45	0.88	0.14	1.23	0.73	0.03	-1.17	-1.48	-1.79			
70% Offered Load								36.81				
85% Offered Load								86.06				
100% Offered Load								106.89				

Table B.177. SIPRNET Circuit Queuing Delay Standard Deviations — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.050	0.048	0.053	0.062	0.061	0.057	0.053	0.051	0.053
Data Overload	0.015	0.021	0.041	0.042	0.106	0.085	0.019	0.037	0.085
Voice Overload	0.202	0.206	0.186	0.333	0.304	0.260	0.130	0.157	0.034
Voice & Data Overload	0.175	0.090	0.046	0.247	0.226	0.372	0.201	0.259	0.178
70% Offered Load								0.466	
85% Offered Load								0.404	
100% Offered Load								4.175	

Table B.178. SIPRNET Circuit Queuing Delay Difference Data — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.40	0.38	0.36	0.30	0.27	0.26	0.28	0.26	0.24
	0.43	0.40	0.37	0.39	0.34	0.32	0.32	0.28	0.27
	0.30	0.26	0.23	0.22	0.18	0.17	0.17	0.14	0.12
	0.34	0.32	0.29	0.28	0.25	0.22	0.23	0.21	0.19
	0.36	0.34	0.30	0.36	0.32	0.29	0.25	0.22	0.21
Data Overload	3.80	3.70	3.54	3.73	3.69	3.67	2.45	2.31	2.23
	3.80	3.69	3.52	3.74	3.74	3.55	2.46	2.39	2.28
	3.78	3.67	3.62	3.81	3.49	3.44	2.47	2.35	2.43
	3.77	3.72	3.55	3.78	3.60	3.52	2.43	2.40	2.24
	3.76	3.66	3.58	3.80	3.75	3.48	2.47	2.38	2.26
Voice Overload	11.47	10.02	8.91	10.04	9.91	8.63	7.01	6.27	5.84
	11.05	9.64	8.38	9.96	9.52	8.11	6.61	6.52	5.77
	11.06	9.78	8.67	10.78	9.66	8.04	6.83	6.50	5.74
	10.89	10.20	8.66	10.28	9.38	8.56	6.82	6.29	5.80
	11.02	9.96	8.44	10.43	9.05	8.13	6.93	6.21	5.73
Voice & Data Overload	16.02	14.86	13.25	15.94	14.44	13.53	10.87	10.37	9.54
	15.76	14.65	13.26	15.75	14.65	13.26	10.68	10.04	9.71
	15.67	14.84	13.29	15.44	14.89	13.58	10.91	10.66	10.02
	15.54	14.72	13.23	15.96	14.90	12.62	11.03	10.38	9.63
	15.63	14.68	13.15	15.50	14.46	13.15	11.20	10.05	9.75
70% Offered Load								13.83	
								13.79	
								12.90	
								13.24	
								14.15	
85% Offered Load								43.63	
								44.63	
								43.69	
								43.56	
								41.90	
100% Offered Load								35.70	
								23.10	
								29.77	
								17.08	
								15.71	

Table B.179. SIPRNET Circuit Queuing Delay Difference Means — DBA-3

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.37	0.34	0.31	0.31	0.27	0.25	0.25	0.22	0.21
Data Overload	3.78	3.69	3.56	3.77	3.66	3.53	2.46	2.37	2.29
Voice Overload	11.10	9.92	8.61	10.30	9.50	8.29	6.84	6.36	5.78
Voice & Data Overload	15.72	14.75	13.24	15.72	14.67	13.23	10.94	10.30	9.73
70% Offered Load								13.58	
85% Offered Load								43.48	
100% Offered Load								24.27	

Table B.180. SIPRNET Circuit Queuing Delay Difference Standard Deviations — DBA-3

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.053	0.052	0.057	0.065	0.065	0.060	0.056	0.055	0.057
Data Overload	0.018	0.022	0.037	0.038	0.109	0.088	0.018	0.036	0.082
Voice Overload	0.221	0.218	0.209	0.329	0.319	0.278	0.150	0.143	0.047
Voice & Data Overload	0.183	0.096	0.052	0.242	0.222	0.384	0.194	0.262	0.182
70% Offered Load								0.501	
85% Offered Load								0.986	
100% Offered Load								8.474	

Table B.181. SIPRNET Circuit Queuing Delay Difference 90% Confidence Intervals — DBA-3

	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
Offered Load	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	0.32 0.42	0.29 0.39	0.26 0.36	0.25 0.37	0.21 0.33	0.19 0.31	0.20 0.31	0.17 0.27	0.15 0.26
Data Overload	3.76 3.80	3.67 3.71	3.53 3.60	3.74 3.81	3.55 3.76	3.45 3.61	2.44 2.47	2.33 2.40	2.21 2.37
Voice Overload	10.89 11.31	9.71 10.13	8.41 8.81	9.99 10.61	9.20 9.81	8.03 8.56	6.69 6.98	6.22 6.50	5.73 5.82
Voice & Data Overload	15.55 15.90	14.66 14.84	13.19 13.29	15.49 15.95	14.45 14.88	12.86 13.59	10.75 11.12	10.05 10.55	9.55 9.90
70% Offered Load								13.11 14.06	
85% Offered Load								42.54 44.42	
100% Offered Load								16.19 32.35	

Table B.182. SIPRNET Circuit Queuing Delay Main Effects — DBA-3

Factor	Variable Designation	Level 1	Level 2	Level 3	Level 4
Workload	A	-7.21	-3.80	2.59	8.41
Allocation Granularity	B	0.82	0.66	-1.48	N/A
Monitoring Period	C	0.50	0.04	-0.54	N/A

Table B.183. SIPRNET Circuit Queuing Delay Second Order Interaction Effects — DBA-3

Allocation Granularity (B)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
8 kbps	-0.76	-0.38	0.53	0.61
32 kbps	-0.67	-0.24	0.18	0.73
64 kbps	1.43	0.62	-0.71	-1.34

Monitoring Period (C)	Workload (A)			
	Underload	Data Overload	Voice Overload	Voice/Data Overload
5 s	-0.47	-0.40	0.39	0.48
10 s	-0.04	-0.04	0.03	0.05
50 s	0.52	0.44	-0.42	-0.54

Monitoring Period (C)	Allocation Granularity (B)		
	8 kbps	32 kbps	64 kbps
5 s	0.13	0.07	-0.19
10 s	0.02	0.02	-0.04
50 s	-0.14	-0.09	0.23

Table B.184. SIPRNET Circuit Queuing Delay Third Order Interaction Effects — DBA-3

Offered Load	Allocation Granularity: 8 kbps			Allocation Granularity: 32 kbps			Allocation Granularity: 64 kbps		
	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)	Monitoring Period (5)	Monitoring Period (10)	Monitoring Period (50)
System Underload	-0.13	-0.01	0.14	-0.06	-0.03	0.09	0.19	0.04	-0.23
Data Overload	-0.12	-0.01	0.13	-0.05	-0.02	0.07	0.17	0.03	-0.21
Voice Overload	0.21	-0.05	-0.16	-0.02	0.04	-0.02	-0.18	0.00	0.18
Voice & Data Overload	0.04	0.07	-0.11	0.13	0.01	-0.14	-0.18	-0.08	0.25

Table B.185. SIPRNET Circuit Queuing Delay Analysis of Variance — DBA-3

SSY	SS0	SSA	SSB	SSC	SSAB	SSAC	SSBC	SSABC	SST	SSE
27223.33	20372.49	6476.77	198.96	32.84	107.61	25.39	2.83	2.75	6850.84	3.68
		Var Due to Workload 94.54%	Var Due to Allocation Granularity 2.90%	Var Due to Monitoring Period 0.48%	Var Due to Workload & Allocation Granularity 1.57%	Var Due to Workload & Monitoring Period 0.37%	Var Due to Allocation Granularity & Monitoring Period 0.04%	Var Due to All Factors 0.04%		Var Due to Error 0.05%
DOF_Y 180	DOF_0 1	DOF_A 3	DOF_B 2	DOF_C 2	DOF_{AB} 6	DOF_{AC} 6	DOF_{BC} 4	DOF_{ABC} 12	DOF_T 179	DOF_E 144
		MSA 2158.924	MSB 99.482	MSC 16.422	MSAB 17.935	MSAC 4.232	MSBC 0.707	MSABC 0.229		MSE 0.026
		F_{compA} 84443.330	F_{compB} 3891.109	F_{compC} 642.328	F_{compAB} 701.517	F_{compAC} 165.527	F_{compBC} 27.649	$F_{compABC}$ 8.953		
		F_{TableA} 2.20	F_{TableB} 2.41	F_{TableC} 2.41	$F_{TableAB}$ 1.90	$F_{TableAC}$ 1.90	$F_{TableBC}$ 2.06	$F_{TableABC}$ 1.68		
		P-valueA 2.005E-233	P-valueB 4.670E-126	P-valueC 1.767E-72	P-valueAB 6.476E-104	P-valueAC 4.994E-62	P-valueBC 4.892E-17	P-valueABC 1.153E-12		

Table B.186. NIPRNET Circuit Traffic Analysis Data

Offered Load	Exponential Interarrivals	Pareto (a=1.1)	Pareto (a=1.4)	Pareto (a=1.6)	Pareto (a=1.7)	Pareto (a=1.9)
System Underload	3.27	3.34	3.31	3.20	3.32	3.27
	3.32	3.43	3.16	3.20	3.20	3.24
	3.18	3.43	3.27	3.21	3.25	3.34
	3.24	3.39	3.28	3.25	3.14	3.16
	3.24	3.49	3.27	3.21	3.29	3.34
Data Overload	4.32	5.99	4.37	4.36	4.35	4.35
	4.38	6.10	4.33	4.35	4.34	4.35
	4.34	3.16	4.30	4.32	4.34	4.34
	4.38	6.58	4.36	4.35	4.28	4.38
	4.38	6.27	4.34	4.31	4.37	4.38
Voice Overload	9.37	9.74	9.33	9.59	9.50	9.51
	9.52	9.95	9.50	9.38	9.54	9.31
	9.30	9.68	9.54	9.44	9.76	9.36
	9.43	9.64	9.67	9.38	9.46	9.47
	9.34	10.39	9.62	9.31	9.31	9.47
Voice & Data Overload	8.89	10.42	9.84	9.06	8.83	8.95
	8.78	14.55	10.59	9.22	9.42	9.07
	9.06	13.17	10.21	9.37	9.85	8.72
	8.92	15.72	9.84	9.41	9.38	8.90
	8.80	16.15	10.87	9.16	9.29	9.09

Table B.187. NIPRNET Circuit Traffic Analysis Means

Offered Load	Exponential	Pareto (a=1.1)	Pareto (a=1.4)	Pareto (a=1.6)	Pareto (a=1.7)	Pareto (a=1.9)
System Underload	3.25	3.42	3.26	3.21	3.24	3.27
Data Overload	4.36	5.62	4.34	4.34	4.34	4.36
Voice Overload	9.39	9.88	9.53	9.42	9.51	9.42
Voice & Data Overload	8.89	14.00	10.27	9.24	9.35	8.95

Table B.188. NIPRNET Circuit Traffic Analysis Standard Deviations

Offered Load	Exponential Interarrivals	Pareto (a=1.1)	Pareto (a=1.4)	Pareto (a=1.6)	Pareto (a=1.7)	Pareto (a=1.9)
System Underload	0.050	0.056	0.058	0.019	0.070	0.073
Data Overload	0.028	1.392	0.029	0.022	0.031	0.020
Voice Overload	0.087	0.311	0.132	0.107	0.161	0.084
Voice & Data Overload	0.110	2.315	0.458	0.145	0.361	0.149

Table B.189. NIPRNET Circuit Traffic Analysis 90% Confidence Intervals

Offered Load	Exponential Interarrivals	Pareto (a=1.1)	Pareto (a=1.4)	Pareto (a=1.6)	Pareto (a=1.7)	Pareto (a=1.9)
	3.20	3.36	3.20	3.19	3.17	3.20
System Underload	3.30	3.47	3.31	3.23	3.31	3.34
	4.33	4.29	4.31	4.32	4.31	4.34
Data Overload	4.39	6.95	4.37	4.36	4.37	4.38
	9.31	9.58	9.41	9.32	9.36	9.34
Voice Overload	9.48	10.17	9.66	9.52	9.67	9.50
Voice & Data	8.79	11.79	9.83	9.10	9.01	8.80
Overload	8.99	16.21	10.71	9.38	9.70	9.09

Table B.190. NIPRNET Circuit Traffic Analysis Data

Offered Load	Exponential Interarrivals	Pareto (a=1.1)	Pareto (a=1.4)	Pareto (a=1.6)	Pareto (a=1.7)	Pareto (a=1.9)
System Underload	3.40	3.64	3.45	3.33	3.43	3.38
	3.43	3.73	3.31	3.33	3.33	3.36
	3.30	3.71	3.43	3.33	3.38	3.45
	3.35	3.65	3.43	3.39	3.28	3.29
	3.37	3.77	3.44	3.35	3.42	3.45
Data Overload	5.91	8.24	6.24	6.02	5.97	5.98
	5.99	5.99	6.23	6.01	5.99	5.98
	5.97	7.61	6.13	6.03	5.95	6.00
	6.01	10.31	6.25	6.05	5.98	6.02
	5.99	7.77	6.18	5.92	5.99	6.04
Voice Overload	10.94	15.60	11.62	11.28	11.24	11.13
	11.26	15.91	11.63	11.23	11.18	10.99
	11.21	15.58	11.52	11.03	11.51	10.96
	11.01	15.47	11.90	11.33	11.10	10.93
	10.93	16.51	12.07	11.28	11.23	11.30
Voice & Data Overload	16.27	27.82	19.49	17.28	16.75	16.40
	15.94	29.26	20.45	17.40	17.33	16.44
	16.56	30.20	20.14	17.92	17.95	16.14
	16.31	28.88	19.45	17.89	17.24	16.33
	15.97	35.21	20.50	17.61	17.20	16.66

Table B.191. NIPRNET Circuit Traffic Analysis Means

Offered Load	Exponential	Pareto (a=1.1)	Pareto (a=1.4)	Pareto (a=1.6)	Pareto (a=1.7)	Pareto (a=1.9)
System Underload	3.37	3.70	3.41	3.34	3.37	3.39
Data Overload	5.97	7.99	6.21	6.01	5.98	6.00
Voice Overload	11.07	15.81	11.75	11.23	11.25	11.06
Voice & Data Overload	16.21	30.28	20.01	17.62	17.29	16.39

Table B.192. NIPRNET Circuit Traffic Analysis Standard Deviations

Offered Load	Exponential Interarrivals	Pareto (a=1.1)	Pareto (a=1.4)	Pareto (a=1.6)	Pareto (a=1.7)	Pareto (a=1.9)
System Underload	0.051	0.057	0.060	0.024	0.062	0.068
Data Overload	0.037	1.551	0.050	0.052	0.016	0.028
Voice Overload	0.157	0.425	0.227	0.115	0.154	0.154
Voice & Data Overload	0.259	2.888	0.509	0.287	0.429	0.188

Table B.193. NIPRNET Circuit Traffic Analysis 90% Confidence Intervals

Offered Load	Exponential Interarrivals	Pareto (a=1.1)	Pareto (a=1.4)	Pareto (a=1.6)	Pareto (a=1.7)	Pareto (a=1.9)
System Underload	3.32 3.42	3.65 3.76	3.35 3.47	3.32 3.37	3.31 3.43	3.32 3.45
Data Overload	5.94 6.01	6.51 9.46	6.16 6.25	5.96 6.05	5.96 5.99	5.98 6.03
Voice Overload	10.92 11.22	15.41 16.22	11.53 11.96	11.12 11.34	11.11 11.40	10.91 11.21
Voice & Data Overload	15.96 16.46	27.52 33.03	19.52 20.49	17.35 17.90	16.88 17.70	16.21 16.57

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Vita

Captain Timothy M. Schwamb was born in July 1973 in Bangkok, Thailand. He graduated from Altus High School in Altus, Oklahoma in May of 1991. He entered undergraduate studies at Oklahoma Christian University of Science and Arts in Oklahoma City, Oklahoma where he graduated Summa Cum Laude with a Bachelor of Science of Electrical Engineering in Electrical Engineering in April 1996. He was commissioned through the Detachment 675 AFROTC at the University of Oklahoma where he was recognized as a Distinguished Graduate and nominated for a Regular Commission.

His first assignment was at Columbus AFB, MS as the Chief of Computer Operations for the 14th Operations Group in July 1996. In June 1997, he attended the Basic Communications Officer Course at Keesler AFB, MS where he was awarded the Armed Forces Communications and Electronics Association Award for leadership and academic excellence. He was then assigned to the 1st Combat Communications Squadron at Ramstein AB, Germany where he served in several capacities culminating in Deputy Commander, Network Systems Flight. While stationed at Ramstein, he deployed to Cervia, Italy in support of Operation SKY ANVIL and also managed the squadron's contingency operations for Operation ALLIED FORCE. In August 2000, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to the 805th Computer Systems Squadron at Scott AFB, IL.

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14. ABSTRACT

Military communications networks typically employ a gateway multiplexer to aggregate all communications traffic onto a single link. These multiplexers typically use a static bandwidth allocation method via time-division multiplexing (TDM). Inefficiencies occur when a high-bandwidth circuit, e.g., a video teleconferencing circuit, is relatively inactive rendering a considerable portion of the aggregate bandwidth wasted while inactive. Dynamic bandwidth allocation (DBA) reclaims unused bandwidth from circuits with low utilization and reallocates it to circuits with higher utilization without adversely affecting queuing delay. The proposed DBA algorithm developed here measures instantaneous utilization by counting frames arriving during the transmission time of a single frame on the aggregate link. The maximum calculated utilization observed over a monitoring period is then used to calculate the bandwidth available for reallocation.

A key advantage of the proposed approach is that it can be applied now and to existing systems supporting heterogeneous permanent virtual circuits. With the inclusion of DBA, military communications networks can bring information to the warfighter more efficiently and in a shorter time even for small bandwidths allocated to deployed sites. The algorithm is general enough to be applied to multiple TDM platforms and robust enough to function at any line speed, making it a viable option for high-speed multiplexers. The proposed DBA algorithm provides a powerful performance boost by optimizing available resources of the communications network.

Utilization results indicate the proposed DBA algorithm significantly out-performs the static allocation model in all cases. The best configuration uses a 65536 bps allocation granularity and a 10 second monitoring period. Utilization gains observed with this configuration were almost 17\% over the static allocation method. Queuing delays increased by 50% but remained acceptable, even for real-time traffic.

15. SUBJECT TERMS

Dynamic Bandwidth Allocation, Circuit-Switched Communication, Time-Division Multiplexing, Tactical Military Communications Networks, Video Teleconferencing Bandwidth

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